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# Data acquisition and control for multiple composite life tests

Emery, James W.

Monterey, California. Naval Postgraduate School

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## Monterey, California



# THESIS

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Data Acquisition and Control for  
Multiple Composite Life Tests

by

James W. Emery, Jr.

June 1988

Thesis Advisor

E. M. Wu

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DATA ACQUISITION AND CONTROL FOR MULTIPLE  
COMPOSITE LIFE TESTS

by

James W. Emery, Jr.  
Lieutenant Commander, United States Navy  
B.S., United States Naval Academy, 1975

submitted in partial fulfillment of the  
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

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## ABSTRACT

Strength durability of composite materials has many current Navy applications including rocket motor cases, pressure vessel for submarine flasks, energy storage for space applications and for pilot ejection seats. The primary effect of composite aging can be characterized by the fiber filament life under constant stress (stress rupture). This thesis develops experimental facilities for parallel testing of fiber filaments in the form of a bundle. A fast data acquisition system records the filaments breakage during load application. The filaments within a bundle sample are maintained at a constant strain level which is automatically adjusted for creep by digital feedback signal from the load of a control sample. A slow speed data acquisition system records filament breakage during long elapse time (days to years). This work establishes a nationally unique capability at the Naval Postgraduate School to quantitatively characterize the reliability of composite material.

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## I. INTRODUCTION

Strength durability of composite materials has many current Navy applications including rocket motor cases, pressure vessel for submarine flasks, energy storage for space applications and for pilot ejection seats. One important manifestation of strength durability is delayed rupture; that is, a structure is intact when initially subjected to a load (i.e., the pressurization of vessel), but as time elapses, the structure experiences a delayed and apparently spontaneous catastrophic failure occurs. This delayed failure or life is associated with the internal aging or damage accumulation within the material. The life statistics of composite material needs to be characterized in order to predict the reliability of structures. The primary effect of composite aging can be characterized by the fiber filament life under constant stress (stress rupture). In order to characterize the statistically random life of a fiber filament the Probability Distribution Function

(pdf) needs to be determined so service life can be predicted. The life pdf can be determined by testing a large number of single filaments individually. This is a time and facility intensive approach. To gain efficiency, filaments can be tested in parallel in the form of a bundle. In such physical configuration, the load carried by the surviving filament members is the Reliability Function which is the complement of the Cumulative Distribution Function (CDF). Differentiating the CDF yields the pdf as shown in Figure 1. From the pdf or CDF, the reliability of a structure can be calculated.

For structures which are subjected to time-varying conditions, load strain history can, as shown in Figure 2, be decomposed into a constant stress component and several components at different frequencies using Fourier decomposition as shown in Figures 3a through 3c. Life under constant stress is known as stress rupture which for rate-insensitive materials dominates the failure mode. Graphite-Epoxy along the fiber direction is rate insensitive, therefore stress rupture statistics are

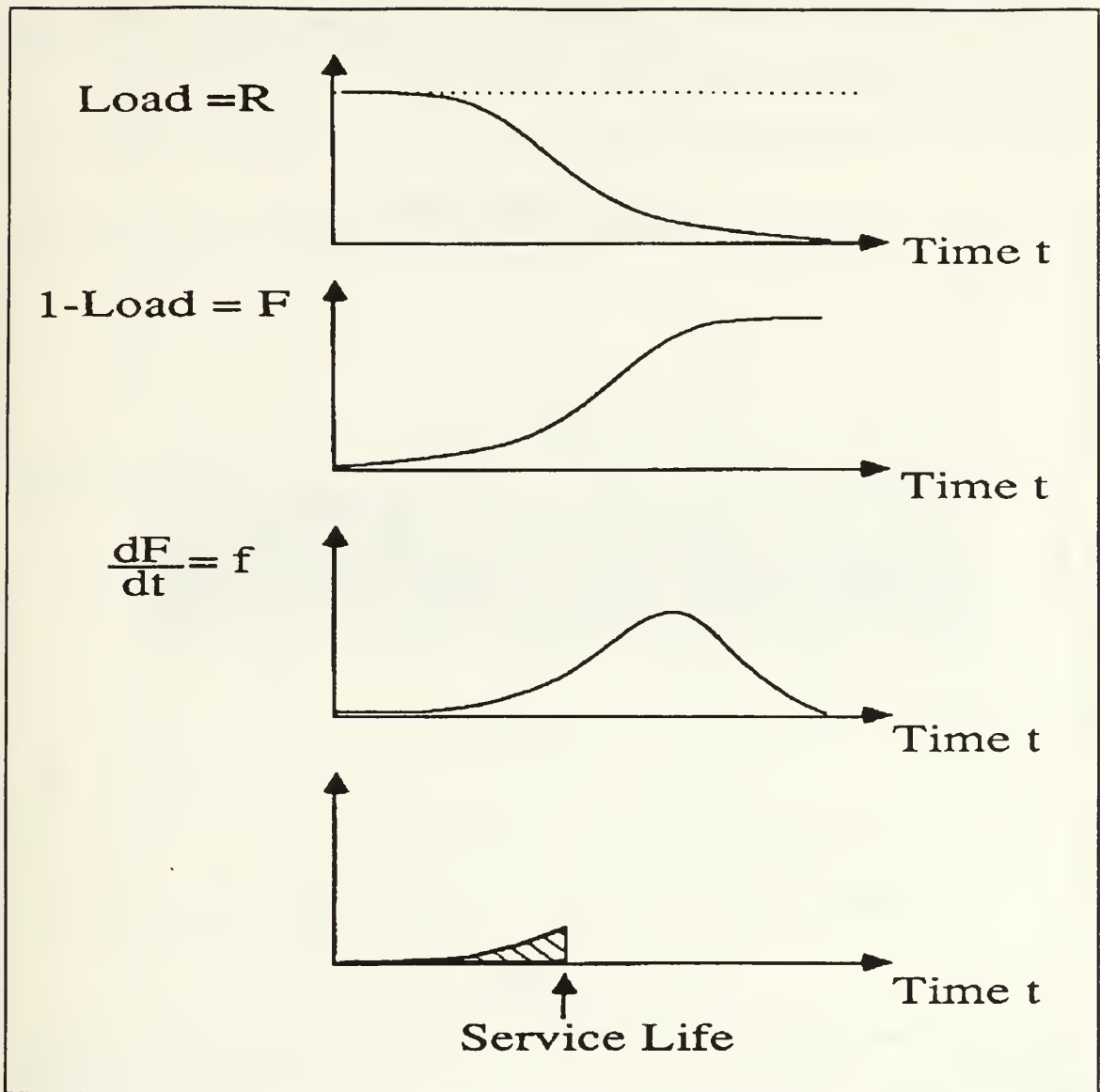


Figure 1  
Requirements

judged to be the most important component for structure life of graphite composite materials.

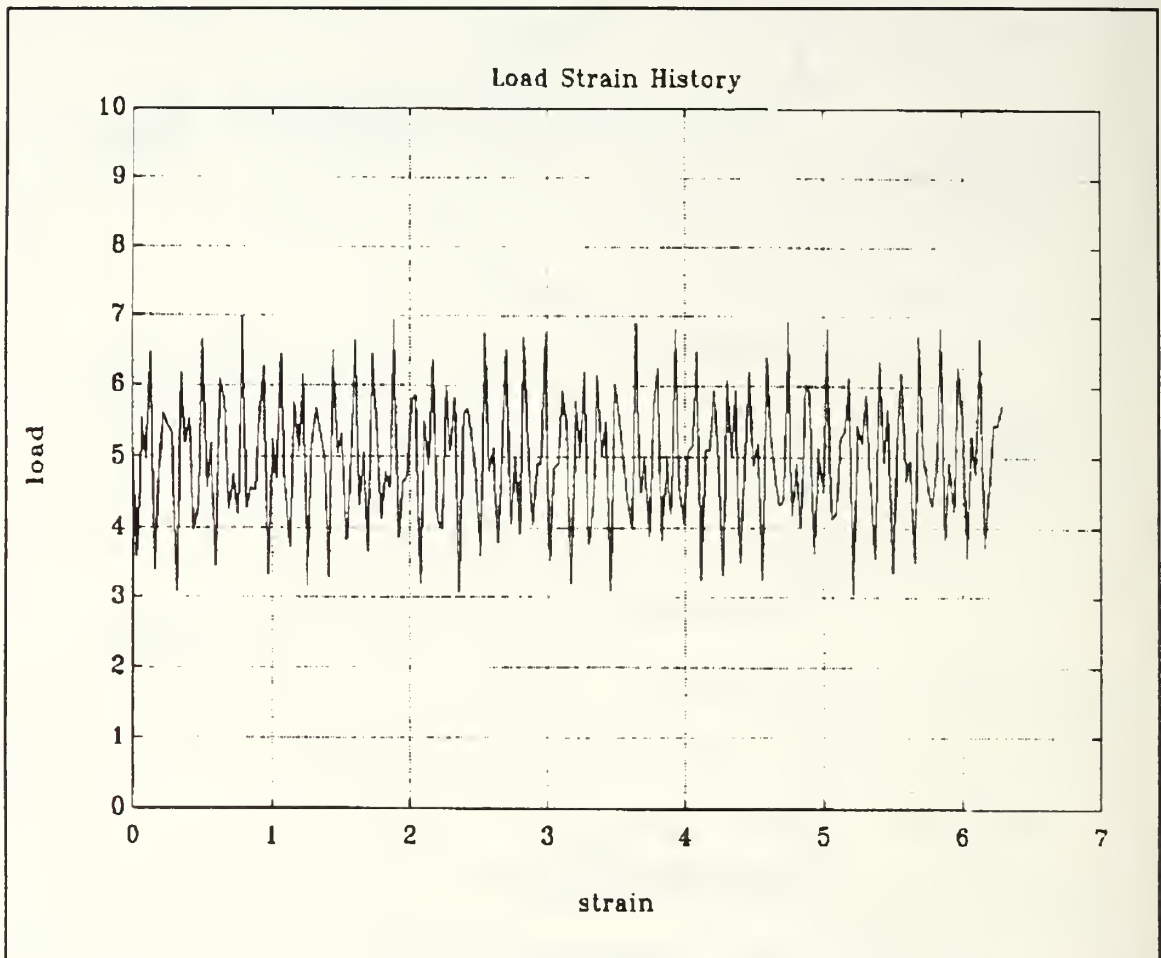


Figure 2  
Load Strain History

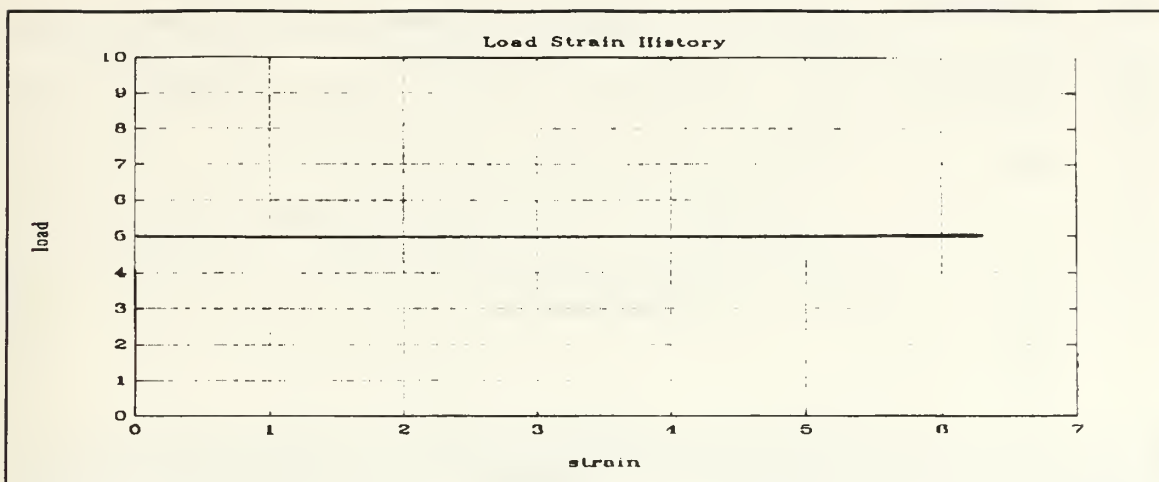


Figure 3a  
Fourier Decomposition

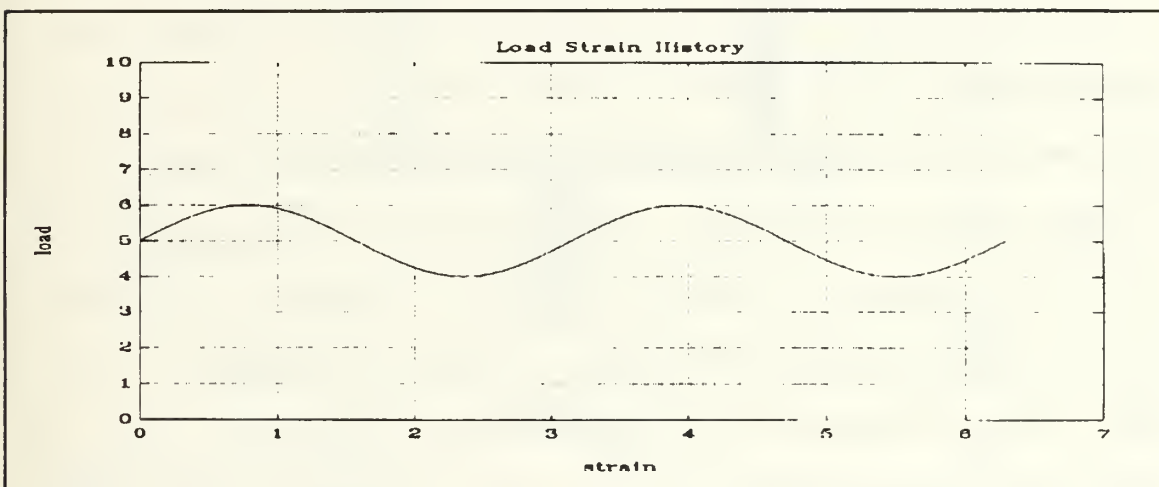


Figure 3b  
Fourier Decomposition



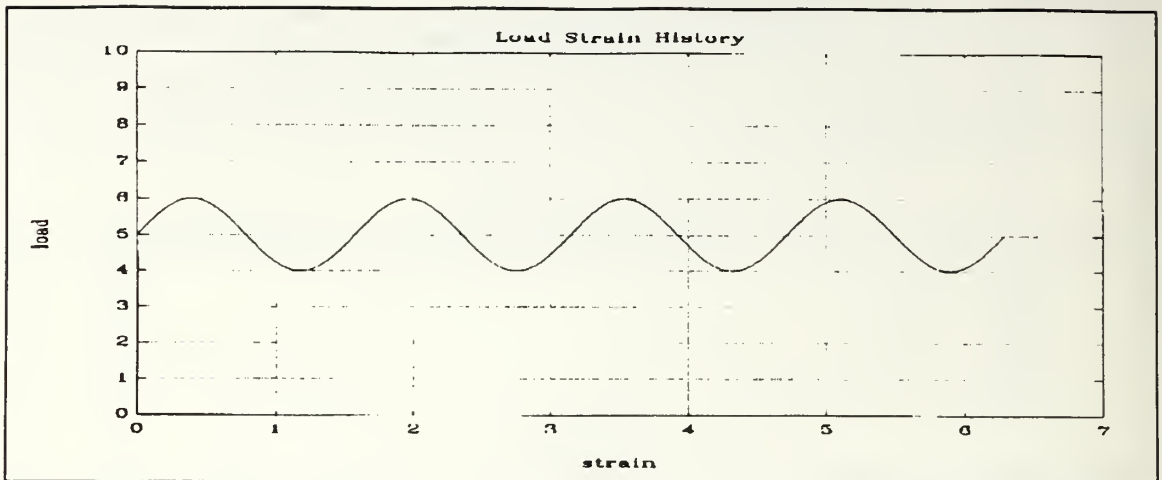


Figure 3c  
Fourier Decompsition

Stress rupture in life for a single filament can be accomplished by hanging a known weight on the filament. The weight and cross sectional area are constant, so the stress remains constant. This testing technique requires extensive space to test the number of samples required to accurately estimate the pdf. A more economical way to test the filaments is to put them in parallel. Parallel testing presents a problem. If a constant weight is suspended from a bundle, the stress on the surviving samples will increase as the filaments break since the effective cross section area of the bundle decreases.

For stress per filament to remain constant, the strain of the filaments needs to be controlled. The stress on each filament is controlled with a sample of the same constituent material as shown in Figure 4.

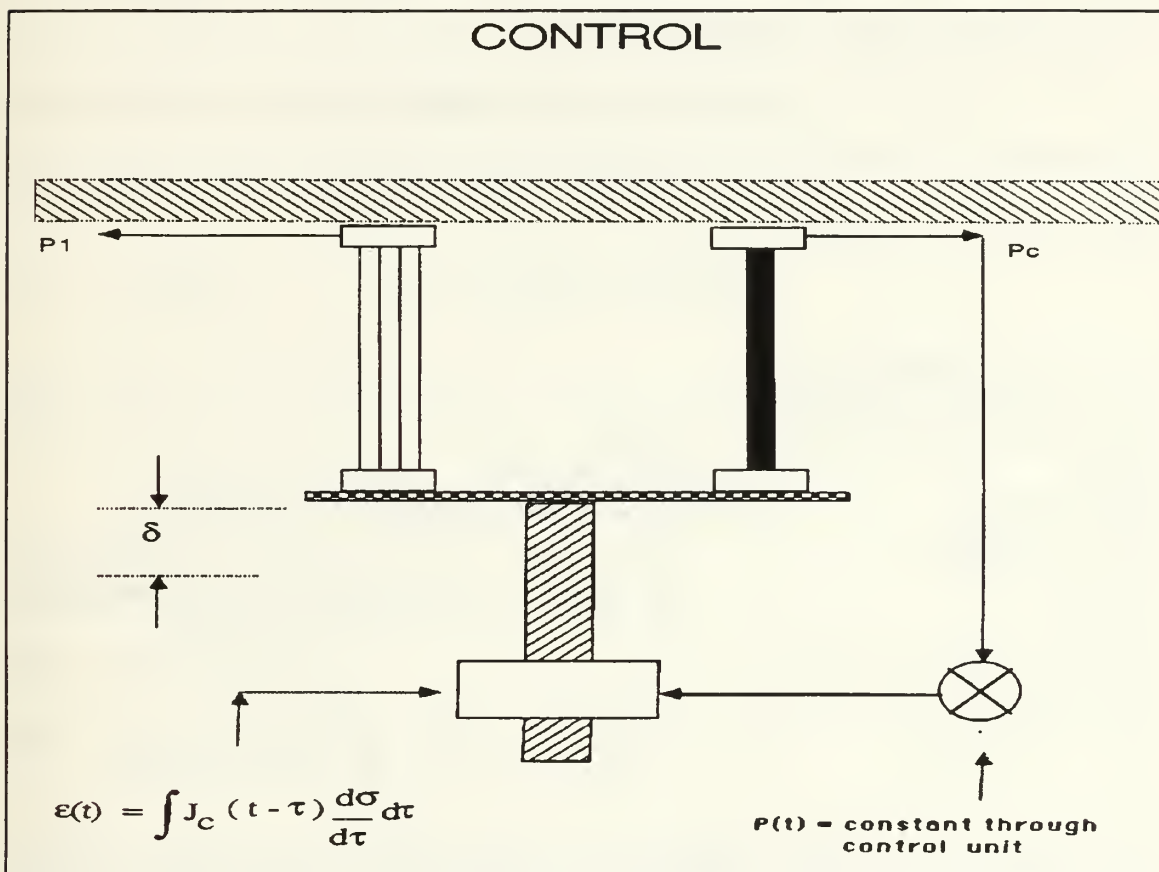


Figure 4  
Control System

The load on the control sample is held constant by a control unit which adjusts the displacement. Since the displacement of the control and test sample are equal, strain of the test sample is adjusted to maintain a constant stress on each filament.

The following derivation demonstrates the underlying mathematical operation for the elastic case and the viscoelastic cases.

$x$ = known parameters		
$x$ = unknown parameters		
Cross-sectional Area	$\tilde{A}_1 \quad A_c$	
Moduli	$\tilde{E}_1 = \tilde{E}_c = \tilde{E}$	same material
Compliance	$\tilde{J}_1 = \tilde{J}_c = \tilde{J}$	same material
Gauge length	$l_1 = l_c = l$	by parallel kinematics
Deformation	$\delta_1 = \delta_c = \delta$	by parallel kinematics
Forces	$P_1 \quad P_c$	by measurement
Number of surviving filaments	$\tilde{n}$	unknown
Cross sectional area of filament	$A_r$	by measurement

If  $A_1$  is known, the number of surviving filaments can be calculated:

$$\tilde{A}_1 = \tilde{n} A_r$$

A. Elastic (time dependent)      B. Viscoelastic (time independent)

$$1. \quad \sigma_1 = \widetilde{E}_1 \varepsilon_1 \quad \sigma_1(t) = \int_0^t \widetilde{E}_1(t-\tau) \frac{\partial \varepsilon(\tau)}{\partial \tau} d\tau$$

Since strains are equal on both samples, the following substitution can be made in Equation 1.

$$\varepsilon_1 = \varepsilon_c \quad \varepsilon_1(t) = \varepsilon_c(t)$$

$$2. \quad \sigma_1 = \widetilde{E}_1 \varepsilon_c \quad \sigma_1(t) = \int_0^t \widetilde{E}_1(t-\tau) \frac{\partial \varepsilon_c(\tau)}{\partial \tau} d\tau$$

The strain on the control sample equals:

$$\varepsilon_c = \widetilde{J}_c \sigma_c \quad \varepsilon_c(t) = \int \widetilde{J}_c(t-\tau) \frac{\partial \sigma_c(\tau)}{\partial \tau} d\tau$$

Substituting into Equation 2:

$$3A. \quad \sigma_1 = \widetilde{E}_1 \widetilde{J}_c \sigma_c$$

$$3B. \quad \sigma_1(t) = \int_0^t \widetilde{E}_1(t-\tau) \frac{\partial}{\partial \tau} \int_0^t \widetilde{J}_c(t-\tau) \frac{\partial \sigma_c(\tau)}{\partial \tau} d\tau d\tau$$

Rewriting the stress as the load divided by area Equation 3 becomes:

$$4A. \quad \frac{P_1}{A_1} = \widetilde{E}_1 \widetilde{J}_c \frac{P_c}{A_c}$$

$$4B. \quad \frac{P_1(t)}{A_1(t)} = \int_0^t \widetilde{E}_1(t-\tau) \frac{\partial}{\partial \tau} \int_0^t \widetilde{J}_c(t-\tau) \frac{\partial}{\partial \tau} \frac{P_c(\tau)}{A_c} d\tau d\tau$$

$A_e = \text{a constant}$

$A_i(t) = \text{a function of time (the number of broken filaments)}$

Rearranging equation 4:

$$5A. \quad \frac{A_e}{A_i} = E_i J_e \frac{P_e}{P_i}$$

$$5B. \quad \frac{A_e}{A_i(t)} = \frac{1}{P_i(t)} \int_0^t E_i(t-\tau) \frac{\partial}{\partial \tau} \int_0^t J_e(t-\tau) \frac{\partial P_e(\tau)}{\partial \tau} d\tau d\tau$$

For the elastic case  $E_i J_i = E_e J_e = 1$  which leads to the direct solution of Eg. 5. However, for the viscoelastic case the relaxation modulus ( $J_e$ ) function and the creep compliance ( $E_i$ ) must be known a priori before the convolution integral can be solved. This convolution integral can be solved experimentally by choosing the test and control samples to be the same material: the feedback control performs the time integral during the actual test.

Figure 5 shows the expected shape of the life curve. From the starting point the load will decrease in time. The test load cannot be applied instantaneously. During the load application phase, the weakest filament will break causing the load to drop to the next line shown in



Figure 6. The next line represents one less filament surviving. If the load was continually increased until all filaments broke the curve would look like Figure 7.

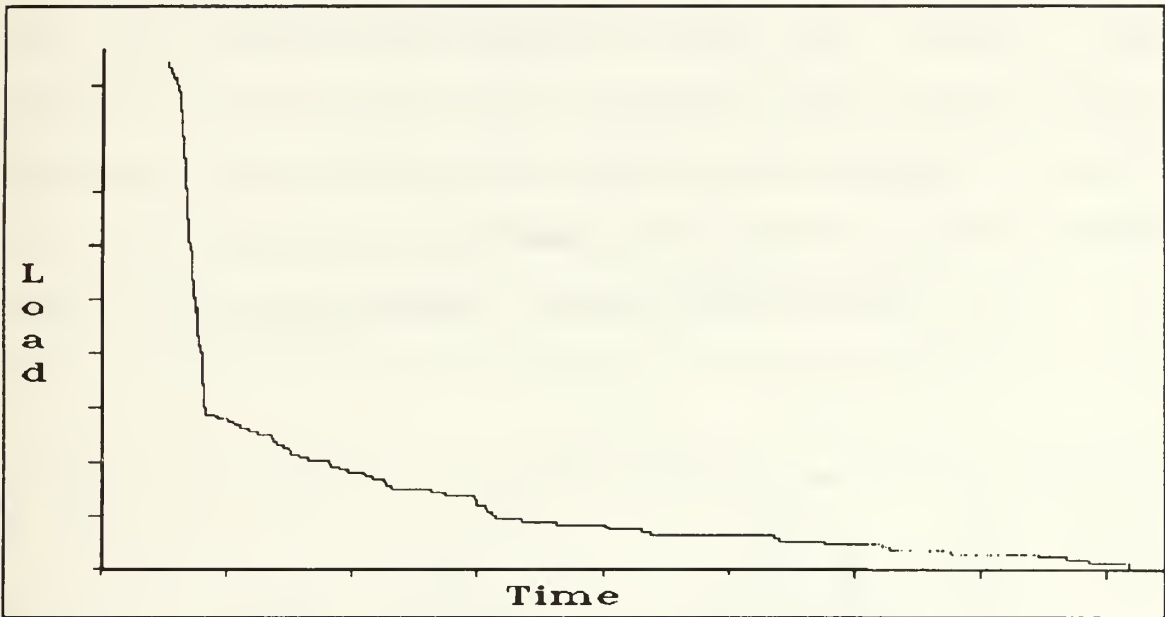


Figure 5  
Simulated Life Curve

Combining these two curves, as shown in Figure 8, the load history will follow the increasing load curve until the test load is reached. After the passage of time the life curve will intercept the constant stress rupture curve and follow it.

The objective of this investigation is to establish an experimental set-up to record the load-time data

during the loading phase and the holding phase. Carozzo, in Ref. 1, first approached this problem by using a scanning digital voltmeter data acquisition system for both phases. He found a faster acquisition rate was needed during the loading phase of testing. Carozzo tried to speed up the acquisition rate through a software modification. He noted his modification proved not to be fast enough during the initial loading period, but the

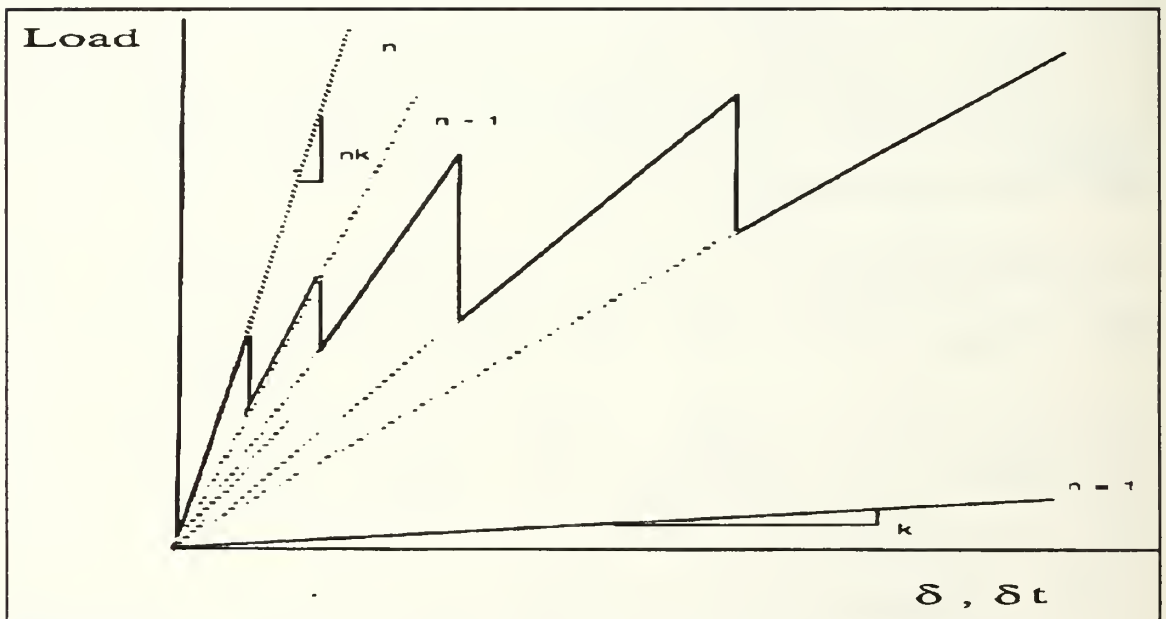


Figure 6  
Initial Loading Breakage

life test portion of his procedure worked satisfactorily. Petridis, in Ref. 2, investigated slowing the loading rate as an alternative to increasing the data acquisition rate. He found the crosshead would stall before a slow enough speed was reached. By combining portions of both studies and incorporating a fast speed acquisition during the loading phase a suitable data acquisition and control system was developed for multiple life tests.

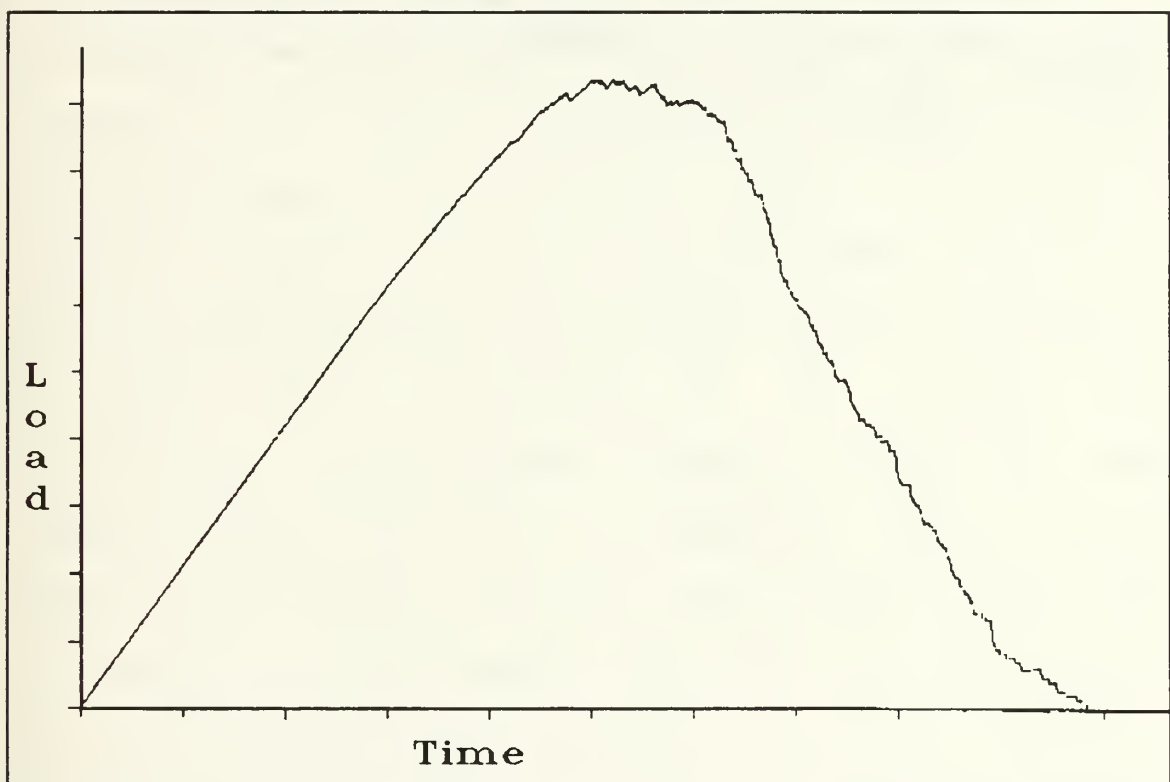


Figure 7  
Simulated Bundle Strength

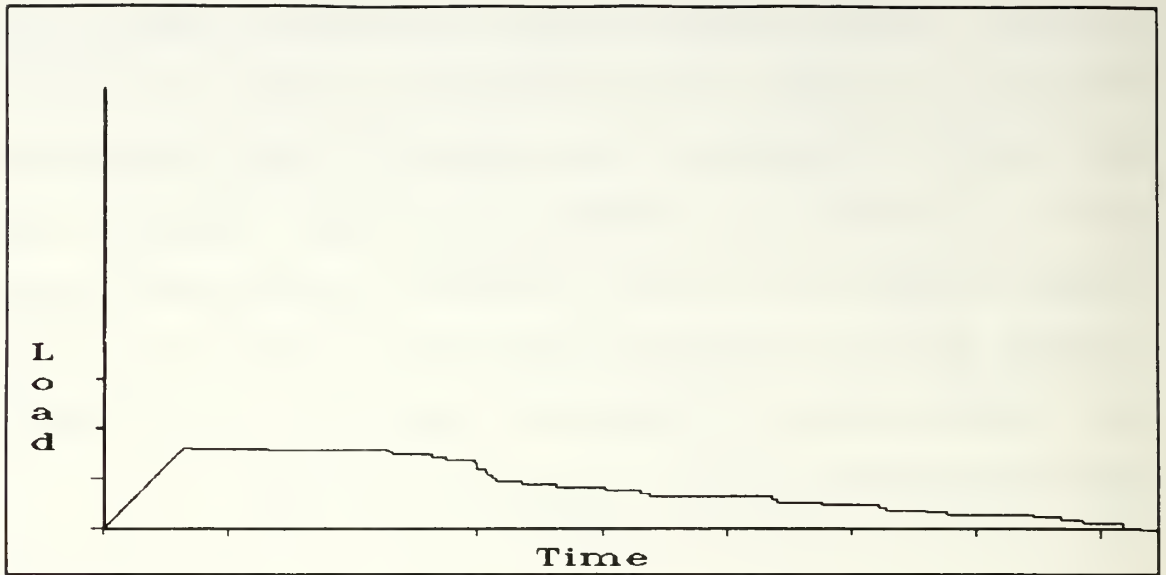


Figure 8  
Simulated Total Life Curve

## II. BACKGROUND

The confidence level in the estimation of statistical parameters is proportional to number of samples tested. A new material without service experience (such as the latest high performance fibers) needs a meaningful estimation of reliability at the level of one out of  $10^3$ , requiring testing of  $10^4$  samples. For life testing the time and resource demand can hardly be considered. On the other hand, high performance fibers are commonly packaged in the form of bundles of  $10^3$  filament or more. Testing bundles (i.e., parallel testing of filaments) realizes an enormous increase in experimental efficiency and therefore a practical way of improving the estimation of lower tail statistics of the strength-life distribution. Nevertheless, bundle testing has many inherent details which must be addressed. Each filament member of the bundle must be of equal length; slack must be removed from all fibers. Friction and entanglement between filaments needs to be minimized (i.e., filaments straightened out) and all the adhesion enhancing coating (sizing) needs to be removed. Advances in experimental



techniques and analytical methodology in data interpretation makes bundle testing viable. High performance composite fiber is stress sensitive (micro-flaw growth). Once a filament is broken, the local stress concentration will cause failure of neighboring fibers. This will result in clustering of the failed filaments which will weaken the structure and eventually cause catastrophic failure of the entire structure. A failure represents the end of life for a filament. By observing many failures the composite structural life Cumulative Frequency Distribution Function (CDF) can be predicted. Appendix A discusses the model for the CDF. When the filament life is known, the composite structural life can be predicated through appropriate mechanics/probability modeling.

To conduct these tests in a reasonable time, stress magnitude amplification compresses the time of the test. Four screw driven testing machines (by Instron Corporation) are configured to test eight bundles in parallel. These testing machines can be used to operate at the same load level or four different levels of load

magnification. For bundles of  $10^3$  filaments, over  $10^5$  filaments can be tested simultaneously.

Life testing can be divided into two phases: loading and testing. These present two separate data acquisition requirements. The data from the loading phase determines how many filaments broke while the load is being applied. This establishes the starting point for the life test, i.e., Life conditioned to survival in strength.

During the loading phase as the load is increased to the test load many filaments will break before it is reached. The decreases in load shown in Figure 6 represent filaments breaking. An experiment having each filament contain only one segment will cause the filaments to break in sequential order, weakest to strongest. This data forms an ECDF for the strength life model. If there is a large drop, several filaments broke together.

Once the desired load is reached then the life testing phase begins. This data is conditional on the filaments surviving the loading. A control system will maintain the load per filament at a constant value. With

a constant load per filament, when a filament breaks, the control system will decrease the total load on the remaining fibers. The total load on the bundle needs to decrease to maintain a constant stress on each filament because the cross sectional area has been reduced.

To measure the CDF, two data acquisition rates are needed. The rate during the loading phase must be fast enough to accurately determine the number of filaments broken during the loading phase. By identifying the part of data which represents the loading before any filaments have broken, the load ( $P_0$ ) which could have been reached if no filaments had broken can be determined. From this selected data a slope can be calculated which will give an equation from which  $P_0$  can be extracted. The difference between the ideal load and the actual load can be related to the number of broken filaments.

Once the test phase begins the acquisition rate can be gradually reduced since over the life of the experiment each reading will become less significant. The slow data acquisition system needs power stability to prevent a loss of data which has been collected for

several years. See Appendix B for a discussion on the selection of hardware for the fast data acquisition system. Carozzo developed the slow data acquisition system in Ref. 1.

The key to bundle testing is keeping each filament in the bundle under a constant stress. Unlike the single filament testing, the test is not completed when a filament breaks. There are 999 tests still in progress in a 1000 filament bundle. The remaining filaments must be kept at the test stress with a control system. If a control system is not installed the surviving filaments after one filament breaks would see an increase in the stress. A control sample will control the stress on the test sample through displacement. Prior to testing the samples (control and test) must be adjusted to the same load so the slack is removed from each test station. If the slack is not removed then a few filaments will not be subjected to the constant test stress. The samples need to rest overnight to remove the viscoelastic effects from the mounting operation.

The friction between the filaments must be minimized. If the filaments are entangled then the bundle will resemble a cable with the filaments supporting each other.

### III. EXPERIMENTAL METHOD

#### A. SAMPLE PREPARATION

The test samples are prepared as detailed by Carozzo in Reference 1. First the sizing must be removed to allow the filaments to act as individual elements. The bundle is then rinsed in alcohol to remove the solvent and sizing residue. The rinse system detailed by Carozzo will ensure the filaments are not entangled and minimize the friction between filaments. Care must be taken to cut the bundle to the gauge length. Bell determined the distribution parameters for a gauge length of ten inches in Ref. 3.

One testing station on the machines will have a control sample instead of a test sample. The control sample is a strand coated with epoxy so the cross sectional area will remain constant. Without the epoxy, the control sample would break like the test sample. If a constant load cannot be maintained on the control sample, the individual filaments of each bundle would not be subjected to a constant stress.

## B. EQUIPMENT AND INSTRUMENTATION

### 1. High Data Rate Acquisition

The bundles will be tested on Instron Model 1000 Universal Testing machines which have been modified with an International Microtronics Corporation Series 700 Control Unit. This modification will compensate the system for creep and will keep the load on the control sample constant.

The control unit reads the load on the control sample and adjusts the crosshead so as to maintain the load on the control sample between the upper and lower load limits. When the test load falls below the lower bound the crosshead increases the displacement until the upper bound is reached. As time increases the load will decrease again, starting a continuous cycle. The control unit load reader needs to be calibrated. it was calibrated over the expected load range 0-15 Kg. See Appendix D for the calibration curve.

The Labmaster DMA card was configured as outlined in Appendix C to run with LABPAC. LABPAC is a program from Scientific Solutions which loads the commands needed to operate the Labmaster Data Acquisition Card into the computer's resident memory. The terminal board as set-up



by Petridis, in Ref 2, proved to be too difficult to use. The distance between the terminals is too short. The number of wires which needed to be added to each terminal created too many possibilities for the introduction of noise. A larger board was also needed to ease set-up, trouble shooting and to help during the preloading of the bundles when a multimeter must be connected.

Once the hardware was in place the load cells and data acquisition card were calibrated for binary and millivolt conversion to load. The load cell selected is the SM series by Interface. This series has the precision strain gauge sealed for more accurate measurements over a wider range of environmental conditions. With the experiment designed to run for years this is important.

The expected load is a function of the number of filaments in a bundle and the beta parameter of the filament model (See Appendix A).

$$\begin{aligned}\text{LOAD}_{\text{expected}} &= (\# \text{ filaments}) * \text{beta} \\ &= (1000) * (15.62 \text{ grams}) \\ &= 15.62 \text{ Kg}\end{aligned}$$

Two versions of the SM series are available: SM50 and SM100. The SM50 does not leave enough margin

for increasing the time compression. The SM100 is the better choice for this composite material since it will allow greater loads to increase the time compression. If a different composite material is tested then the SM50 might be a better choice.

The load cell specification is 3mV/V (output/input). With a recommended excitation voltage of 10V and a maximum load of 45.56Kg for the load cell the expected output at maximum load will be:

$$30 \text{ mV}/45.46\text{Kg} = .66 \text{ mV/Kg}$$

Each load cell was calibrated at 0, 5, 10, 15Kg. The expected readings are:

<u>Load</u>	<u>Expected Output</u>
0	0
5	1.32
10	3.30
15	9.90

Each load cell was loaded up to 15 Kg and then back to zero. The loading was decreased for a hysteresis check. The entire loading/unloading process was repeated for a repeatability check. The range of the data acquisition card with the 500 gain option is -20mV to +20 mV. At 15 Kg the binary readout should be approximately 1023 and

the card should saturate at 20mV. Each load cell was checked using the acquisition program developed for the fast acquisition system.

Appendix D has the calibration curves for both the millivolt and binary to load conversion. The calibration equations will be used to determine the load for a given binary or millivolt reading. All channels on the data acquisition card saturated at 20 mV as calculated. Hysteresis and repeatability were checked. Hysteresis met manufacturer's specifications and the data was repeatable on different tests.

The LVDT, used to measure the distance the bundles are displaced, was calibrated as detailed in Ref. 1. The LVDT's expected output is in the volt range but saturation on the acquisition card occurs at 20 mV. A voltage divider was placed in the circuit as shown in Figure 9 using a metal film resistor vice a carbon one for better accuracy.

With the expected movement being .02-.025 inches of the gauge length (Ref. 3) the output will be:

$$LVDT_{output} = (15.5)(0.25) = .382V$$

$$Acquisition\ Card\ Input = (3.9\ k\Omega / 1.1\ m\Omega) * (.382V) = 1.35mV$$

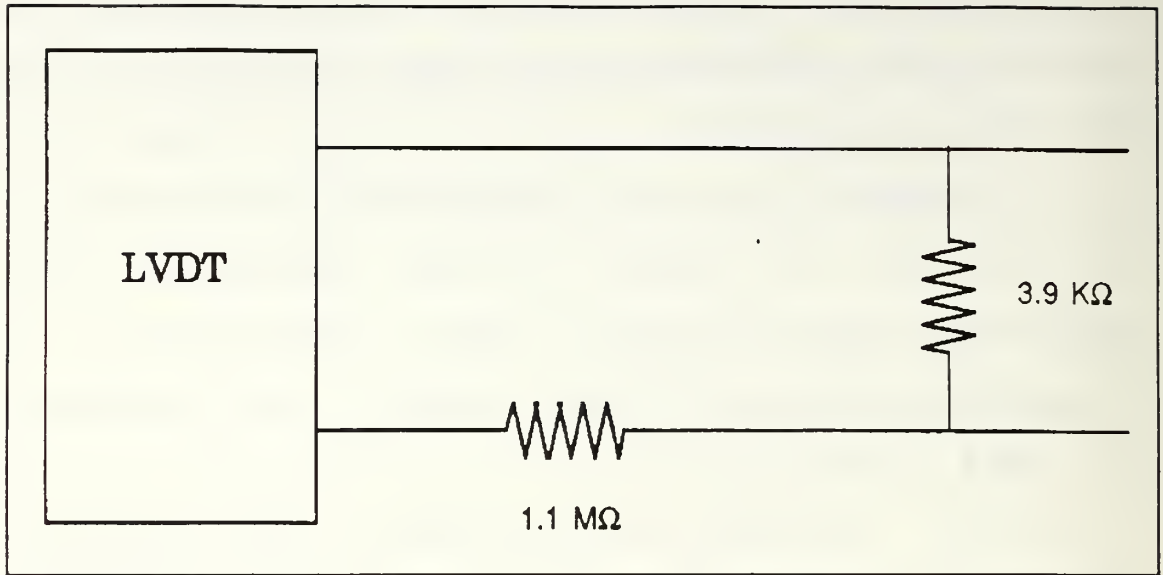


Figure 9  
Voltage Divider

The voltage divider in Figure 9 provides this level of output.

## 2. Slow Data Rate Acquisition

Once the test load has been reached the number of readings required will decrease. This is due to an infant mortality period. As time increases the number of failures will decrease until the life of the bundle is approached. Since we are only investigating the lower tail the increase of failures late in life do not present a problem. This reduction of failures after the loading period results in a reduced reading requirement.

The procedure developed by Carozzo, in Ref. 1, is well suited for this reduced data acquisition requirement. He modified the data acquisition control unit software from Hewlett Packard to speed up the acquisition rate. Since the fast data acquisition is being handled by a different system the original Data Logger program as supplied by Hewlett Packard meets the rate requirements.

The time interval between readings will be reduced in steps, while maintaining a 1% resolution. The larger rate at the start helps to determine the starting point for the life test. A step reduction starts after five minutes of testing and continues for 15 days when the fast system is disconnected. Figure 10 shows how the acquisition rate interval is reduced in steps. The acquisition rates are defined in Table 1. The scalar and numbers of sweeps in the fast data acquisition software in Appendix E were calculated from the data in Table 1. The slow system was then started.

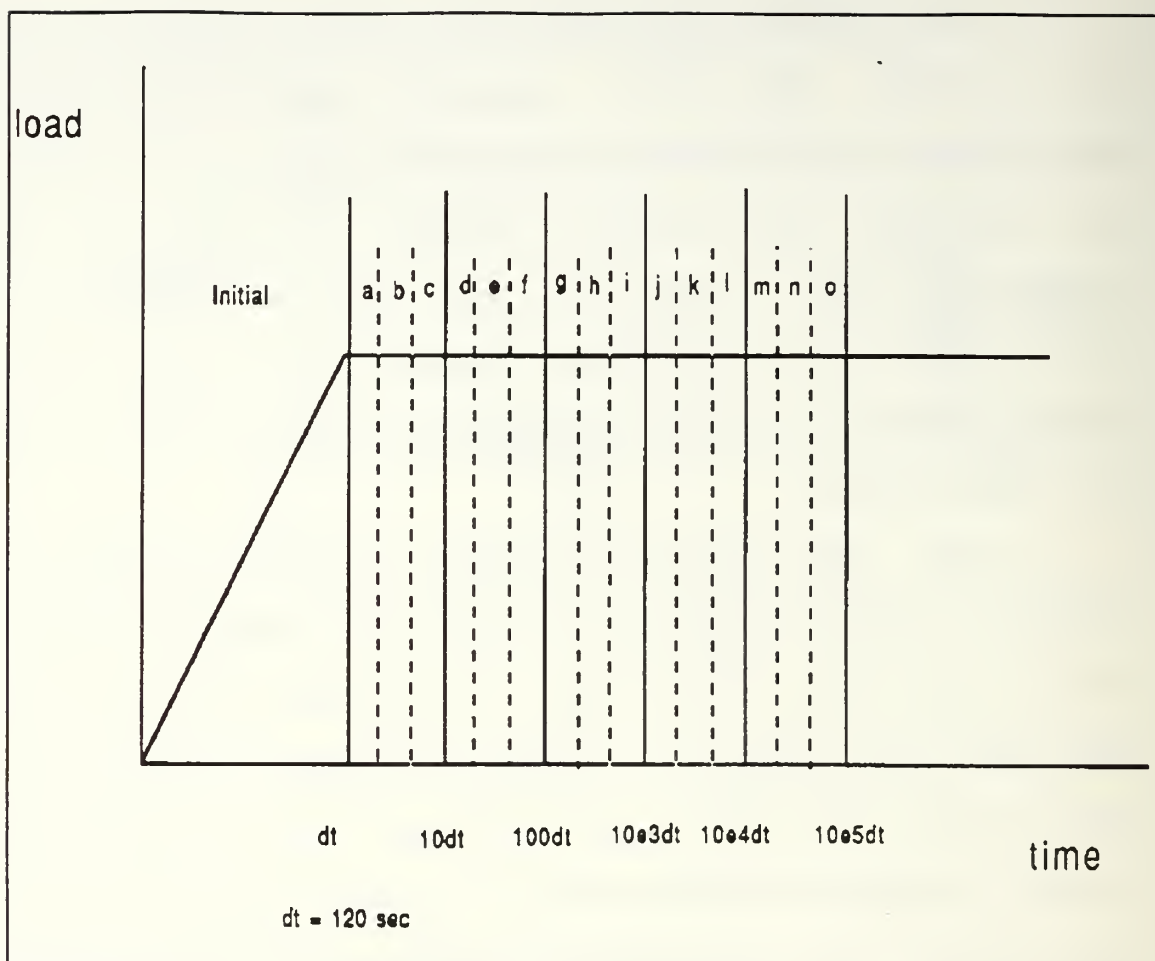


Figure 10  
Time Intervals

TABLE 1  
TIME INTERVALS DEFINED

---

dt = 120 sec

Time Interval	Elapsed Time (sec) te	Reading Rate/ Channel (sec) ts	Rate per Channel (Hz)	ts/te	Readings per Channel per delta T
initial	300	0.100	10.0000	0.0003	3000.0
a	600	6.000	0.1667	0.0100	50.0
b	900	9.000	0.1111	0.0100	33.3
c	1200	12.000	0.0833	0.0100	25.0
d	4800	48.000	0.0208	0.0100	75.0
e	8400	84.000	0.0119	0.0100	49.2
f	12000	120.000	0.0083	0.0100	30.0
g	48000	480.000	0.0021	0.0100	75.0
h	84000	840.000	0.0012	0.0100	49.2
i	120000	1200.000	0.0008	0.0100	30.0
j	480000	4800.000	0.0002	0.0100	18.0
k	840000	8400.000	0.0001	0.0100	10.3
l	1200000	12000.000	0.0001	0.0100	7.2
m	1560000	15600.000	0.0001	0.0100	5.5
n	1920000	19200.000	0.0001	0.0100	4.5
p	2280000	22800.000	0.0000	0.0100	3.8

---



## C. SOFTWARE

### 1. High Data Rate System

The manufacturer of the Labmaster Card, Scientific Solutions, provides a program LABPAC which loads the commands necessary to operate the card into resident memory. These commands act as functions which can be called from many high level languages. Documentation for Advanced Basic, C, Fortran and Pascal is provided. A master menu driven program showing the use of all commands is provided in Basic (Ref. 4). The code listing in Appendix E was written using this as a guide. It is also written so no user inputs are required. Most of the program's time is spent in the functions defined by LABPAC. LABPAC's functions are already assembled in machine code so very little time is spent in the Basic driver program. The variable COUNT is defined to the following clocks:

11	1MHz
12	100KHz
13	10KHz
14	1KHz
15	Hz

The clock is divided by a scalar to get the sweep rate. It takes four sweeps to cycle through the four functions of the Labmaster Card. One of the functions is

to read the analog input. To get the reading rate divide the clock by four times the scalar.

The program is written to take data at the desired rate and record it to a file on the hard disk during the loading phase. A different file is created for each data rate to minimize the loss of data if there is a failure. The program LMENUCAL.BAS is used to take binary calibration readings. It takes twenty readings per channel and writes them to the designated file. The code listing is in Appendix E.

## 2. Slow Data Acquisition Rate System

The Data Logger program supplied by Hewlett Packard in its Data Acquisition ROM PAC meets the needs of the data collection requirements after 15 days of testing. The program is prompt driven and is easy to change. The procedures are listed in Appendix F.

#### IV. RESULTS AND CONCLUSIONS

Two trial runs using two test samples each were run at a high and a low test load. The results are graphed in Figures 11 and 12. The system works as expected. The loading phase clearly shows filaments in the test bundle

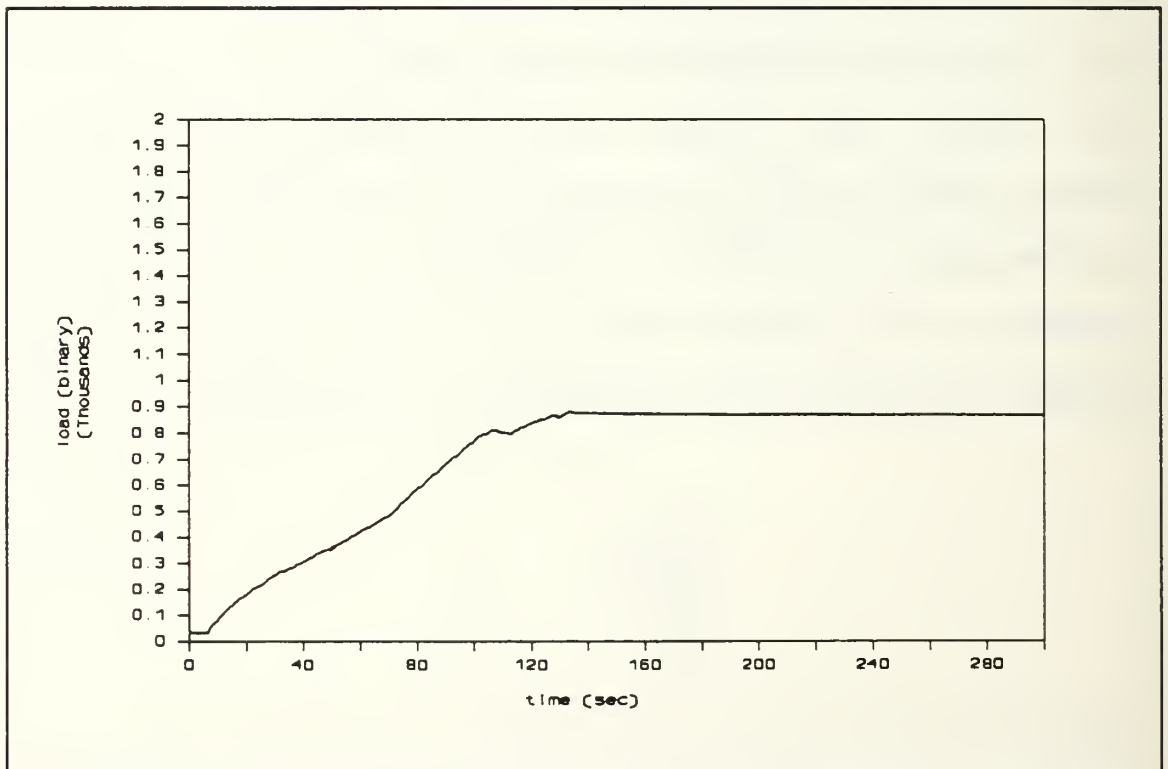


Figure 11  
High Test Load

are breaking. Once the test load is reached the control sample is held at a constant load, keeping the stress per filament in the test sample constant as predicted. On Figure 12 there appears to be a drop in the load just after the test level is reached. The short period of time the trial runs ran is too short to see large drops since the test is designed to run years. Carozzo, in Ref. 1, proved the slow acquisition system worked. To ensure the connecting/disconnecting of the fast data acquisition system did not affect the slow system's reading a check was made to see what would happen. The readings did not change with a known load on the load cells.

The procedures in Appendices F and G collect the data required to establish the life PDF of the graphite filaments.

A better means of mounting the control sample needs to be investigated. It cannot be mounted the same as the test samples. During a test with it mounted the same as the test samples, it failed at the grip. For the next run the control sample was glued in a copper tube. The control sample slipped out of the grip. The control sample was then glued in the copper tube which was then

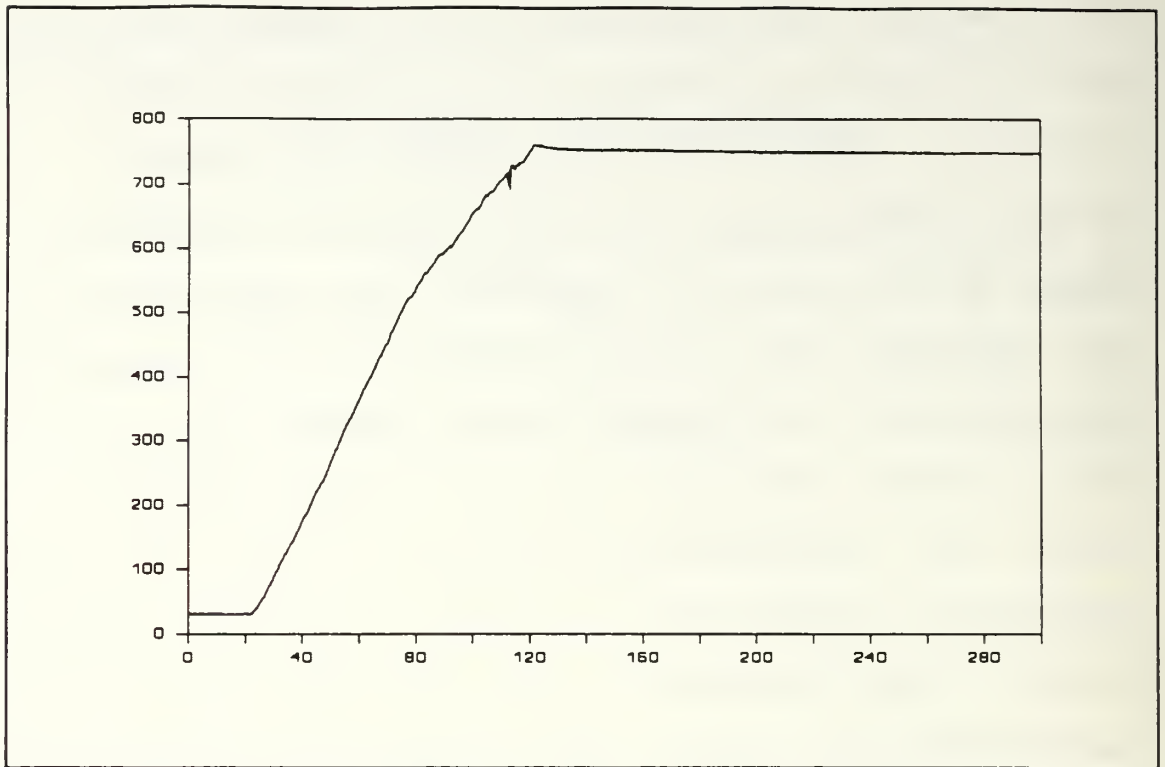


Figure 12  
Low Test Load

placed in a larger copper tube. This appears to have stopped the slipping but at higher loads it might slip again.

## LIST OF REFERENCES

1. Carozzo, F.D., Experimental Procedure for Lifetime Testing of Graphite Bundles Under Constant Load, Master's Thesis, Naval Postgraduate School, Monterey, California, March 1986.
2. Petridis, D.M., Composite Service Life Prediction via Fiber bundle Testing Equipment and Data Acquisition System, Master's Thesis, Naval Postgraduate School, Monterey, California, December 1986.
3. Bell, D.K., Composite Reliability Enhancement via Preloading, Master's Thesis, Naval Postgraduate School, Monterey, California, June 1987.
4. LABPAC USER'S GUIDE, Scientific Solutions Presses, Solon, Ohio, 1987.

## APPENDIX A Model Selection

Composite failure is best represented by a weakest link theory as in a chain. Where a chain is made with links, composite fiber is built with segments. The Weibull distribution best describes this failure mechanism in a composite fiber.

$$\text{Weibull CDF } F = 1 - \exp \{-(x/\beta)^\alpha\}$$

The distribution has two parameters associated with it, alpha and beta. Alpha corresponds to its shape and beta to its location. Beta is the mean of the distribution but it is not always at the 50% failure point. The distribution's shape is adjustable with the shape parameter, alpha. With an alpha of approximately 3.5, the shape will approximate a normal distribution. To make the results easier to graph and manipulate the Weibull distribution is normalized with respect to beta. F and x become F\* and x\* and are defined as follows:

$$F^* = \ln\{-\ln[1-\exp(-P/\beta)^\alpha]\}$$
$$x^* = P/\beta$$

With P being the load the filament is being subjected to during the test. The true values of these parameters are



not known. Many samples must be tested in the lab to find what they are for a given gauge length. The testing of composite fiber starts with the testing of a fiber length (l). This length is arbitrary and can vary depending on the application being studied. From testing in the lab the distribution parameters can be determined. Bell, in Ref. 3, determined alpha and beta for a gauge length of ten inches.

$$l = 10 \text{ inches} \quad \alpha = 5 \quad \beta = 15$$

A bundle consists of many filaments of length (L) where L is divided into many segments (n) where:

$$n = L/l$$

## APPENDIX B Equipment Selection

The objective is to collect data from ten load cells three times a second during the initial loading phase. The data will be put into a spreadsheet for further manipulation. Long term stability is required since the experiment will run for years. Losing two years of data due to a power failure is not acceptable.

Carozzo, in Ref. 1, developed the current slow data acquisition system. He found the system shown in Figure B1 did not provide enough data points during the initial loading phase to obtain a reliable description of the time/life curves. The HP3421A (DVM) A/D converter cannot be speeded up enough nor can the Instron crosshead be slowed to obtain the minimum satisfactory rate of 3 readings a second per channel [Ref. 2]. The options considered are shown in Figures B2 and B3. Figure B2 shows the option recommended by Carozzo. Using the HP computer the data still needs to be transferred to a spreadsheet. This can be done but it is time intensive. Figure B3 shows an option using the MacAdios with a Macintosh. An additional MacAdios and a Macintosh computer would be needed. Figure B4 shows an IBM with a

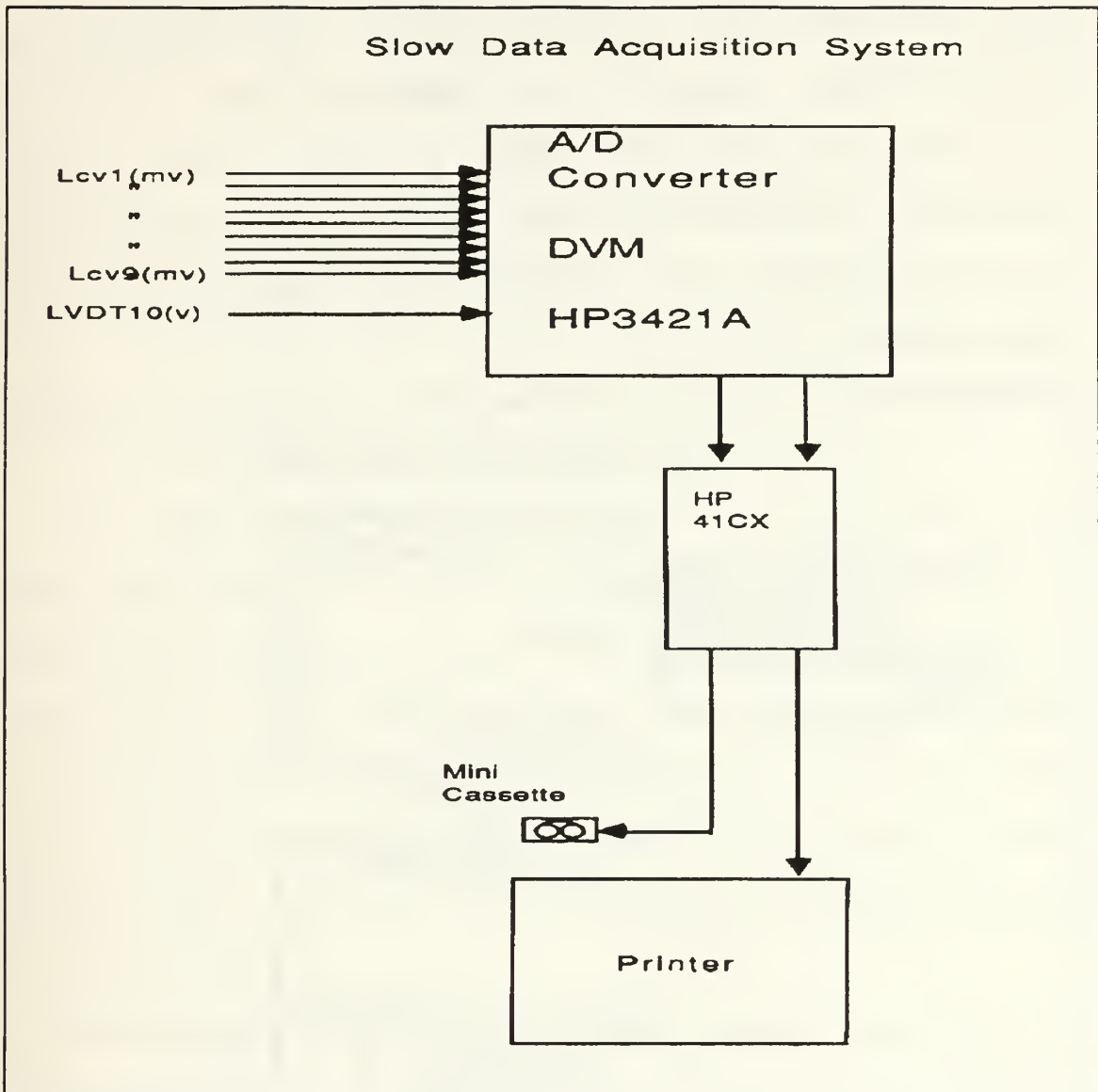


Figure B1  
Slow Data Acquisition System

Scientific Solutions Labmaster Card. The only equipment needed in this option is the Labmaster Card. The card has a programmable gain option for low voltage inputs. Software is supplied with the card to transfer the data to a spreadsheet. As a backup Assyt/Assytant Plus are available in the lab.

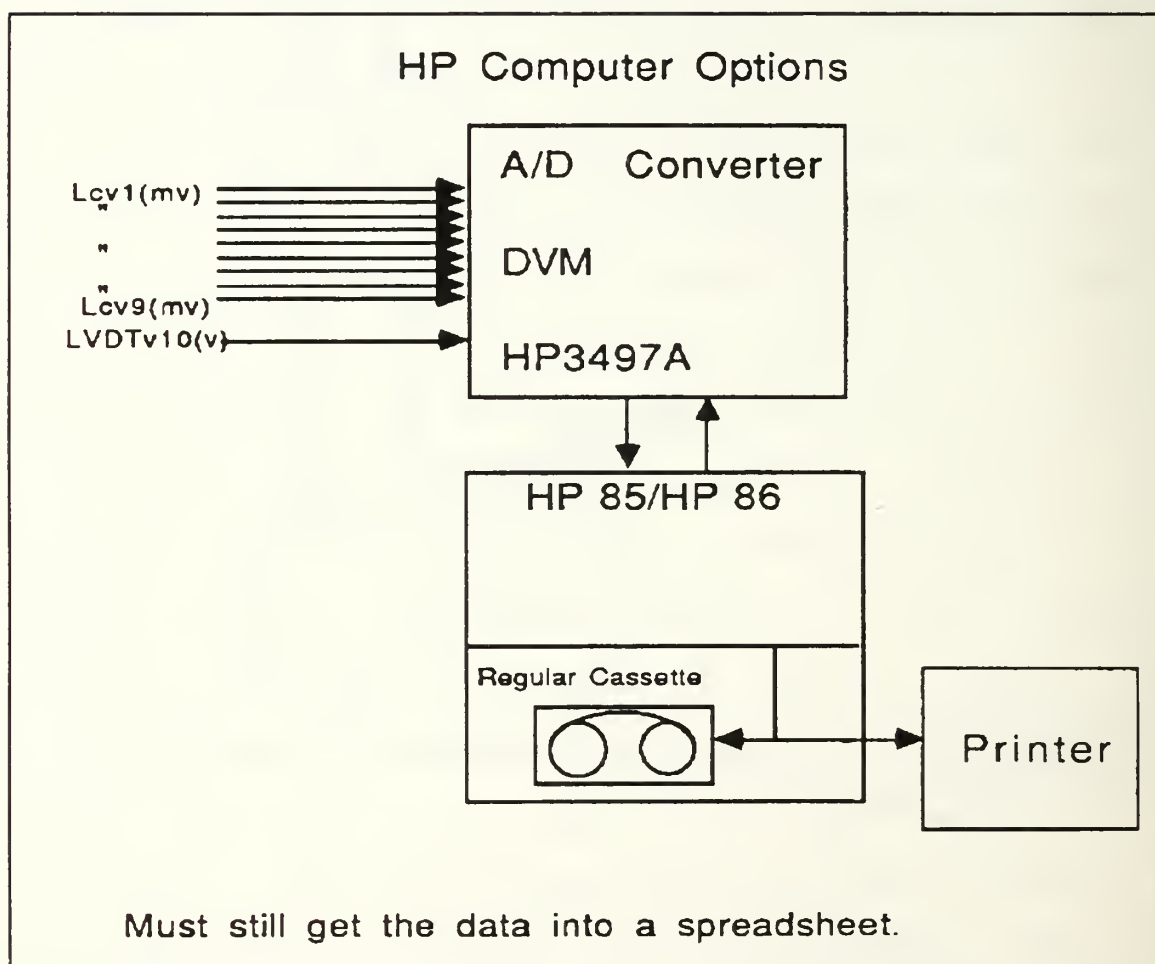


Figure B2  
HP Option

The switching from the high to low rate could cause problems if the impedance of the two systems do not match. It could be very difficult to match the impedances. Instead of trying to match impedances the other option is to block the fast rate set-up so the fast data acquisition system will draw an extremely small amount of current. The Labmaster Card has an impedance of 100 meg-ohms, more than enough.

The IBM option with the Labmaster Card, Figure B4, was chosen due to: the programmable gain option, the impedance matching problem and an IBM AT computer is available in the Composite Lab. The computer will only be needed for a short time during the initial loading after which it can be used for other experiments. After fifteen days the slow data acquisition system in Figure B1 will be used.

The problem of getting the data taken with the slow data acquisition system into the spreadsheet could be solved by using an HP IL card for the IBM and software to translate the HP41 data into code readable by the IBM. After testing the procedure the time involved proved to be too great. It is easier and quicker to just enter the data directly into the spreadsheet.

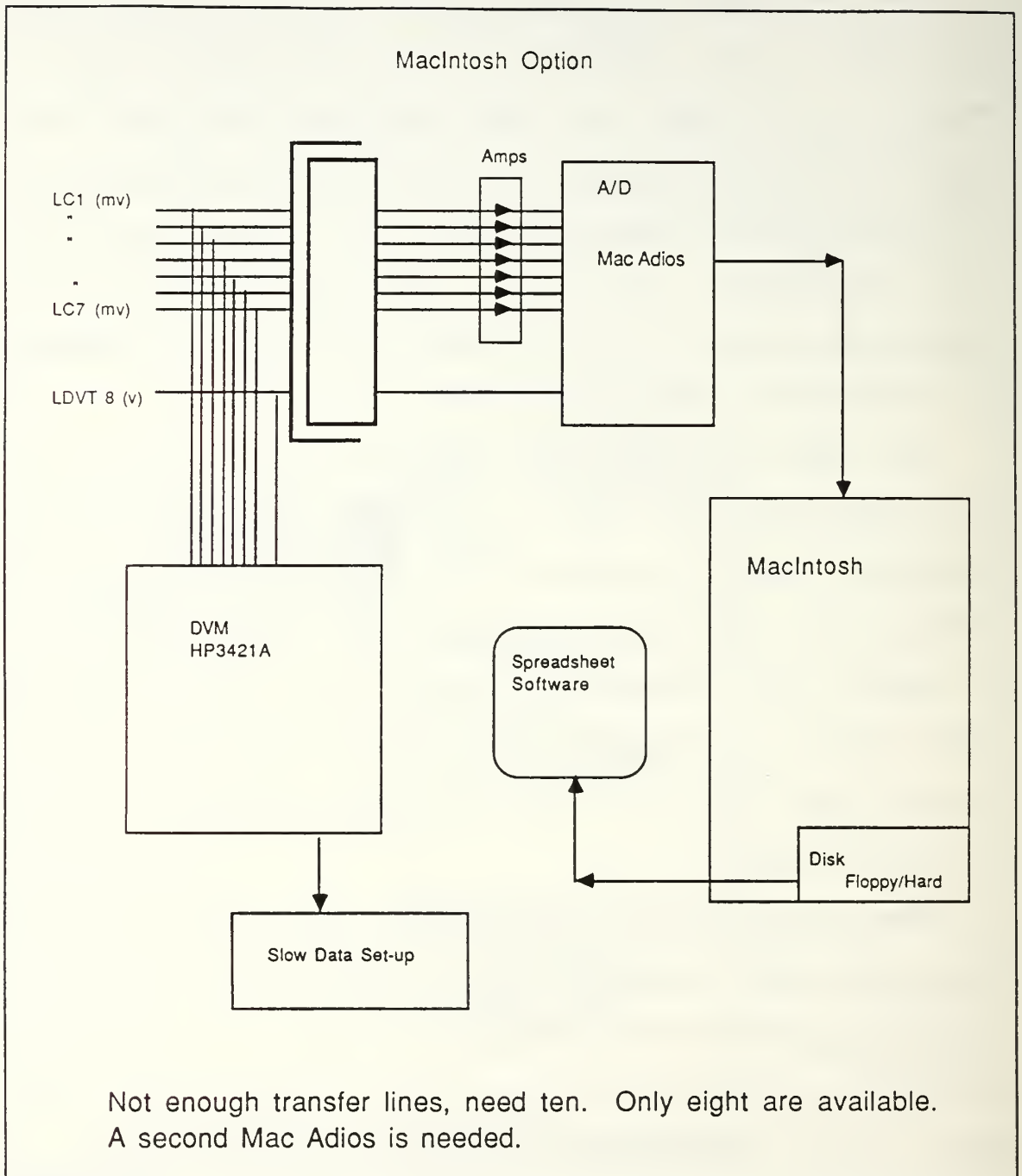


Figure B3  
MacIntosh Option

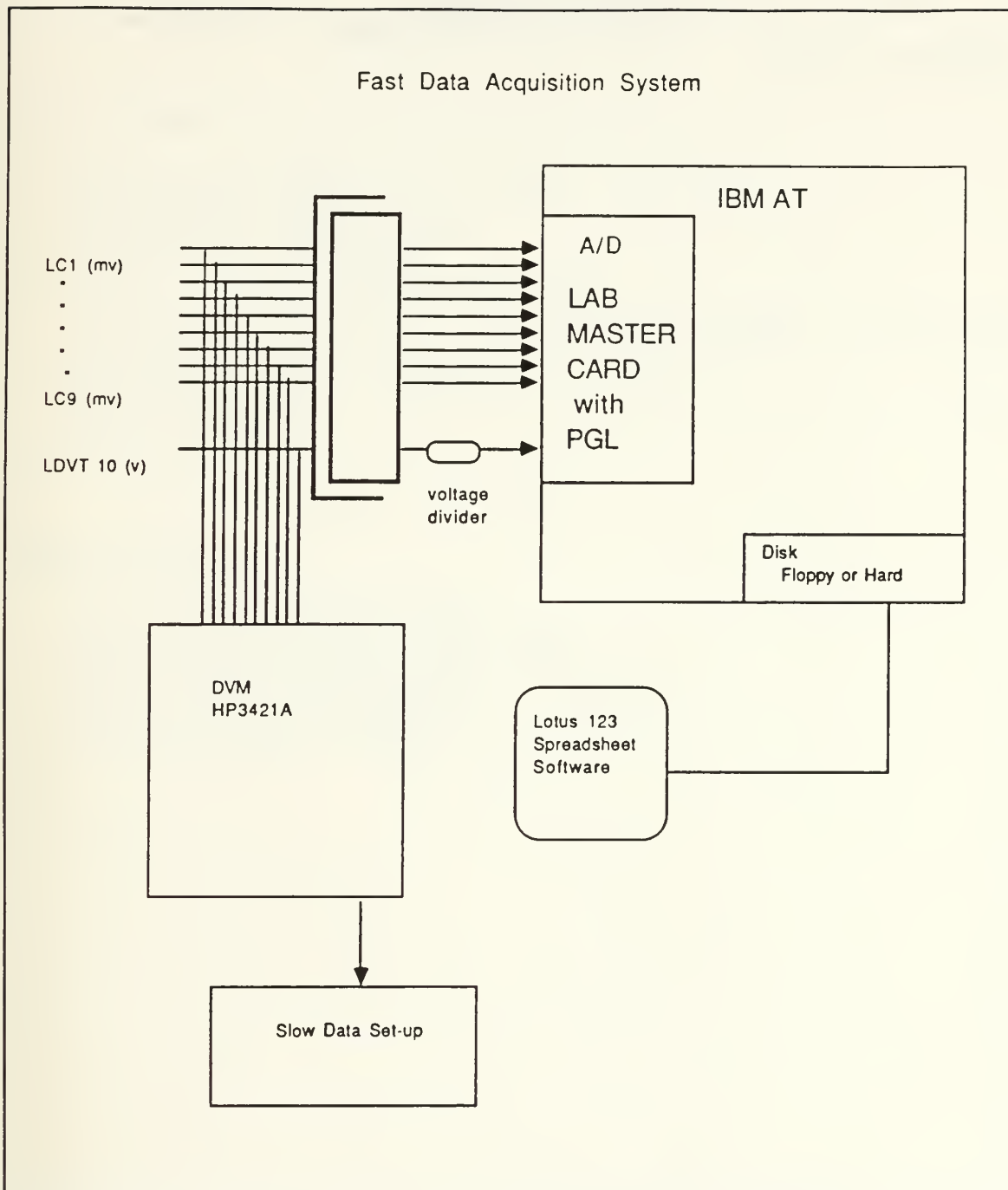


Figure B4  
Fast Data Acquisition System



Lotus 123 Spreadsheet software is available in the  
Composite Lab.

APPENDIX C  
Labmaster Board Set-Up

Mother Board:

Memory Base Set of 0710 hex  
I/O mapped mode set  
Enabled Ws (connected)  
J5 to 4 wait states  
Pins 7 and 14 connected on J4  
TINT set for counter 1 to directly trigger interrupts  
J7 set to zero  
Dack/Dreq set to channel 1  
ESOC enabled  
Done enabled

Daughter Board:

JSD to true differential  
JAD to bipolar with PGL, PGH  
JCD to true differential, normal  
JDD to two's complement  
JBD to normal/overlap

## APPENDIX D Calibration Curves

This Appendix is organized as follows:

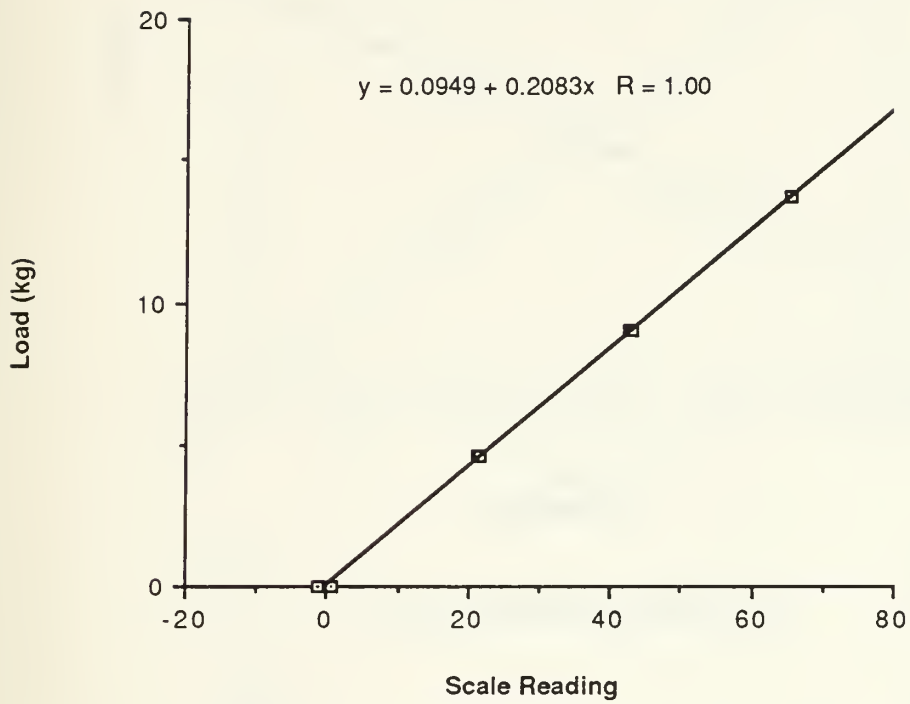
Instron Control Unit Graph

LDVT Graphs

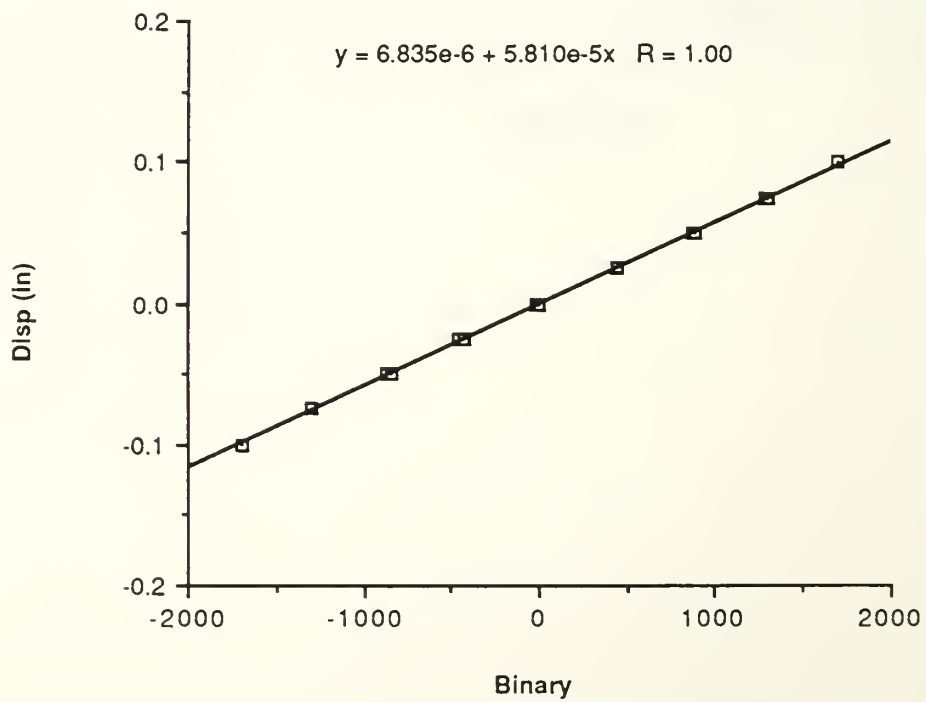
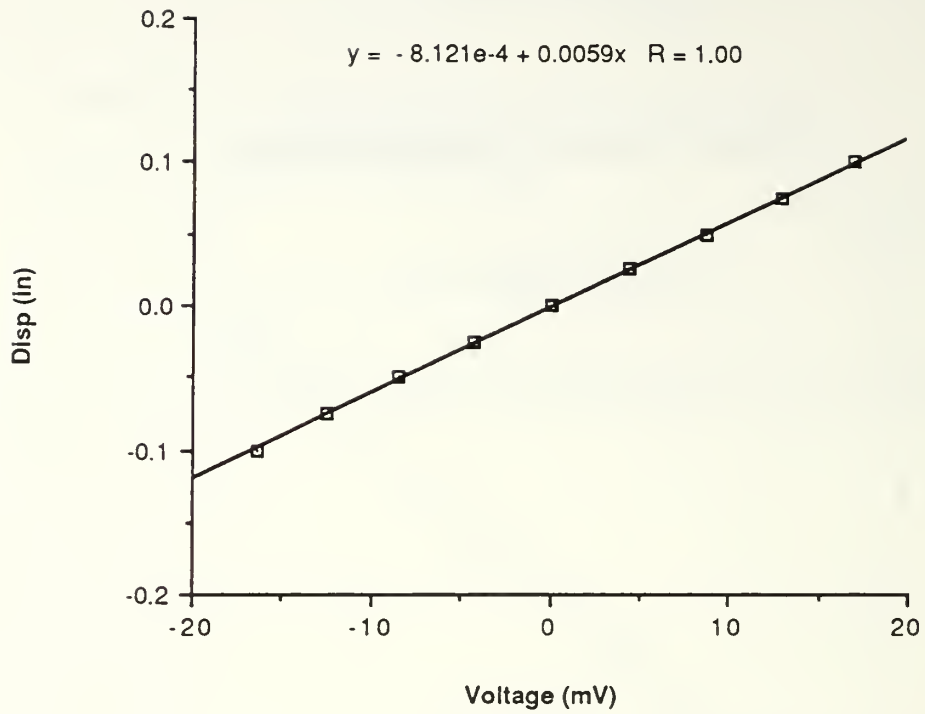
Load Cell Graphs

Note: The R value for the curve fit is an indication of how well the equation matches the data.  $R = 1.00$  is an excellent fit.

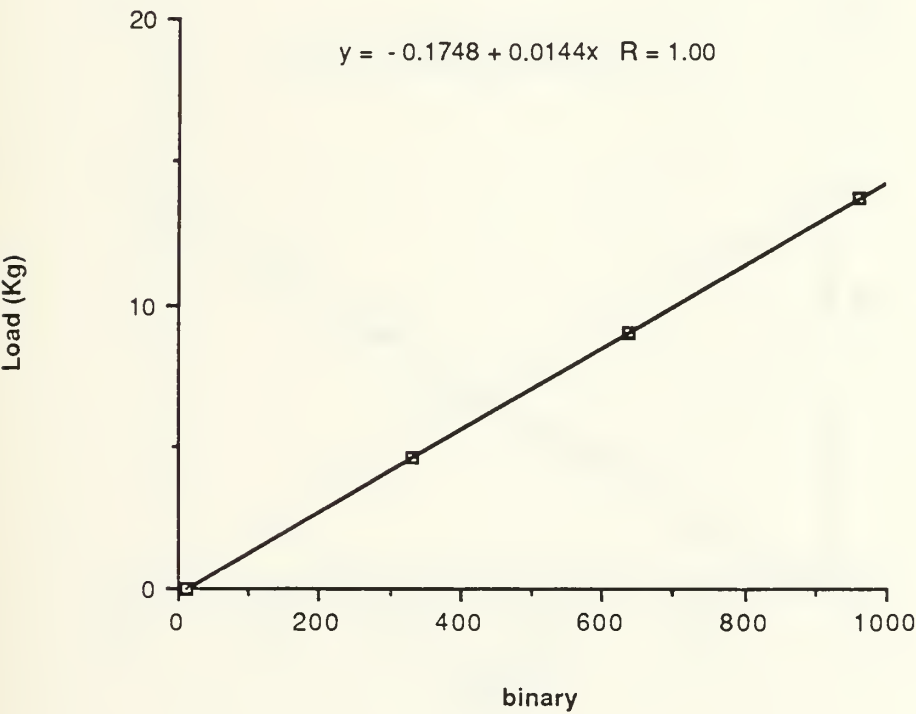
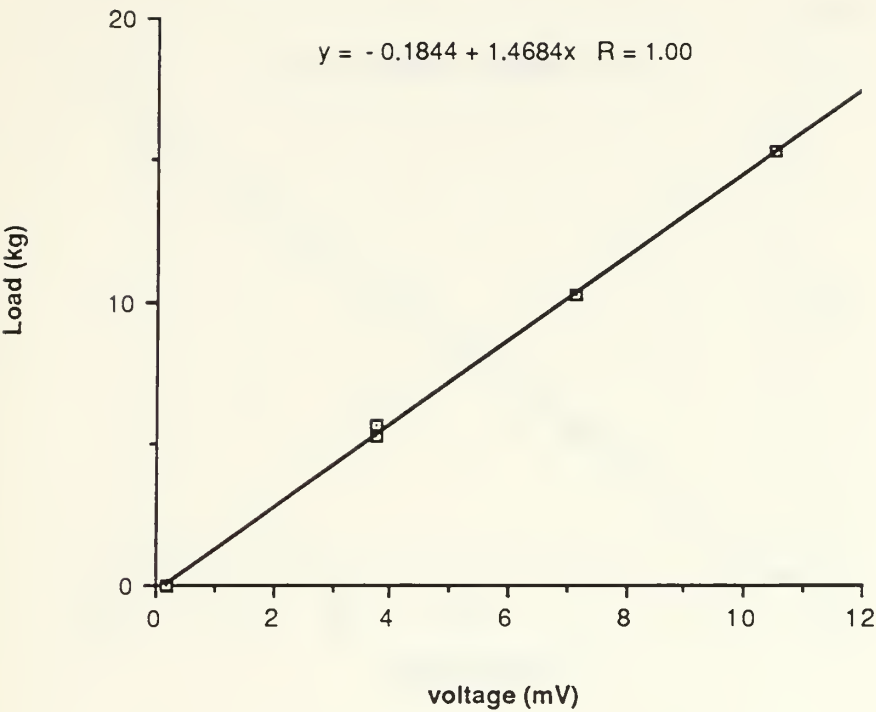
## Instron Contol Unit Calibration



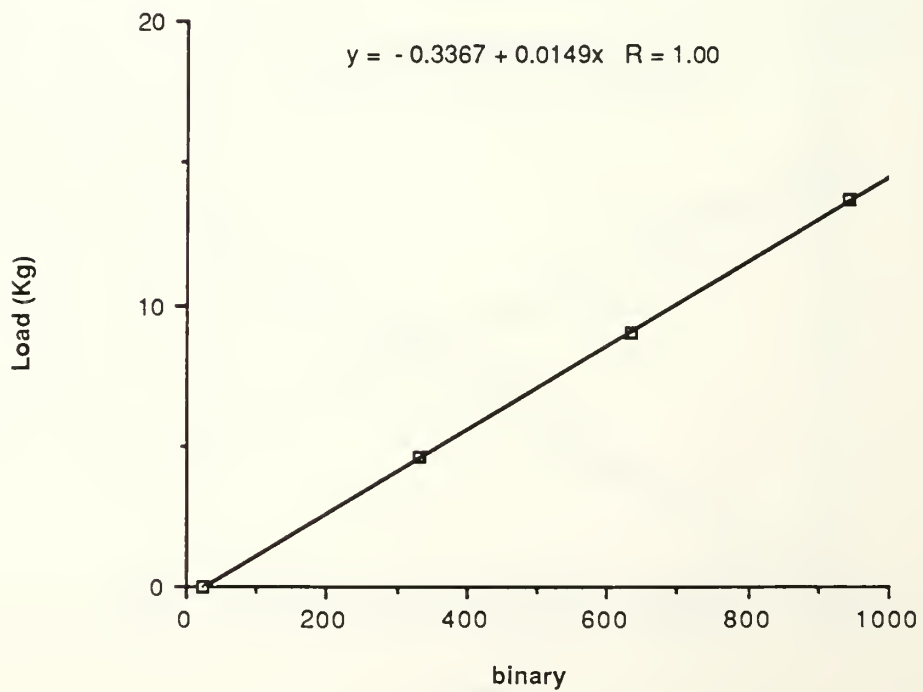
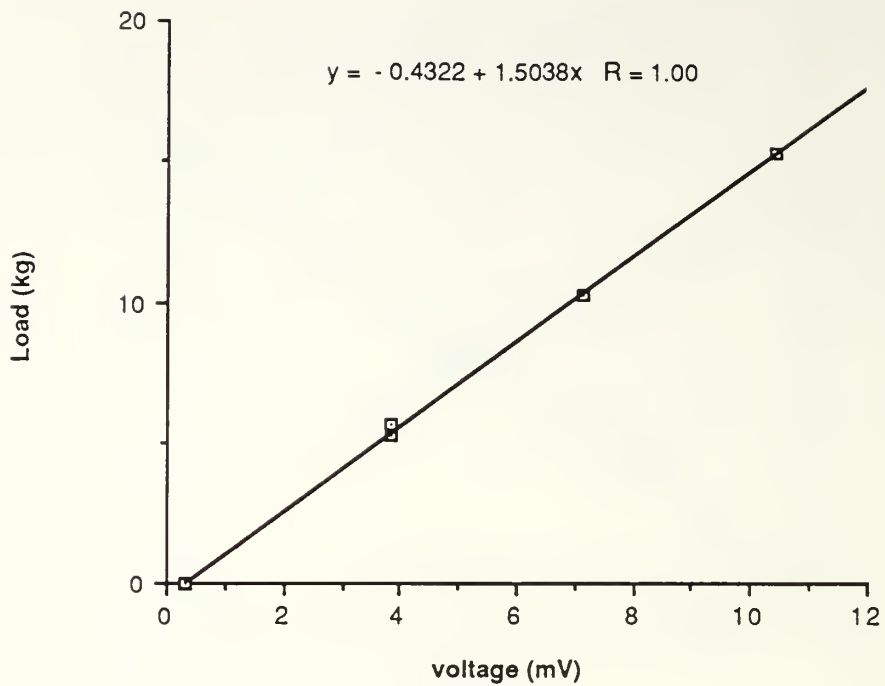
## LDVT Calibration



# Load Cell 1 Calibration

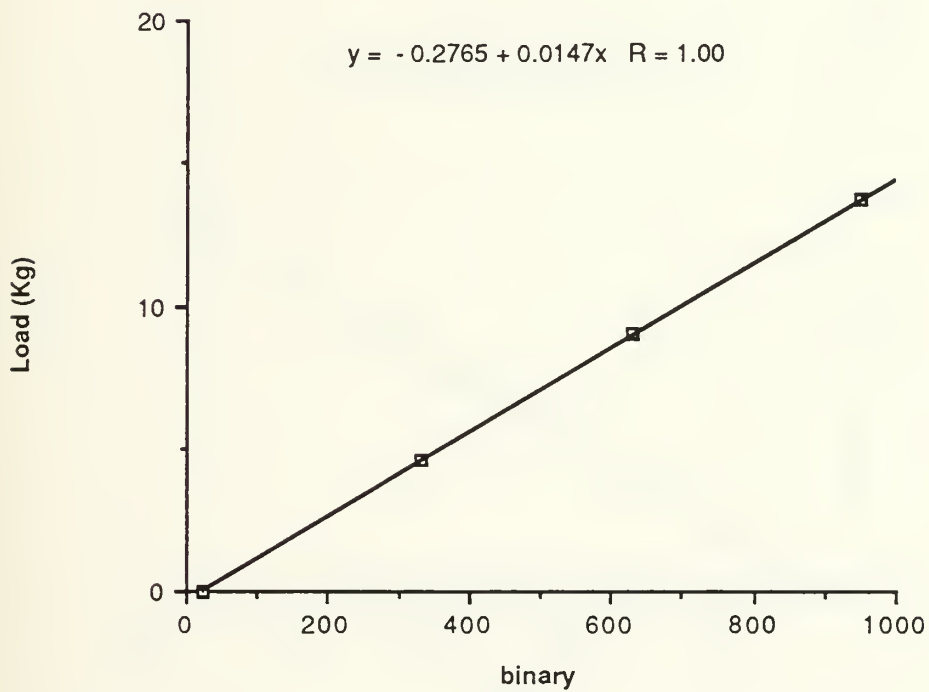
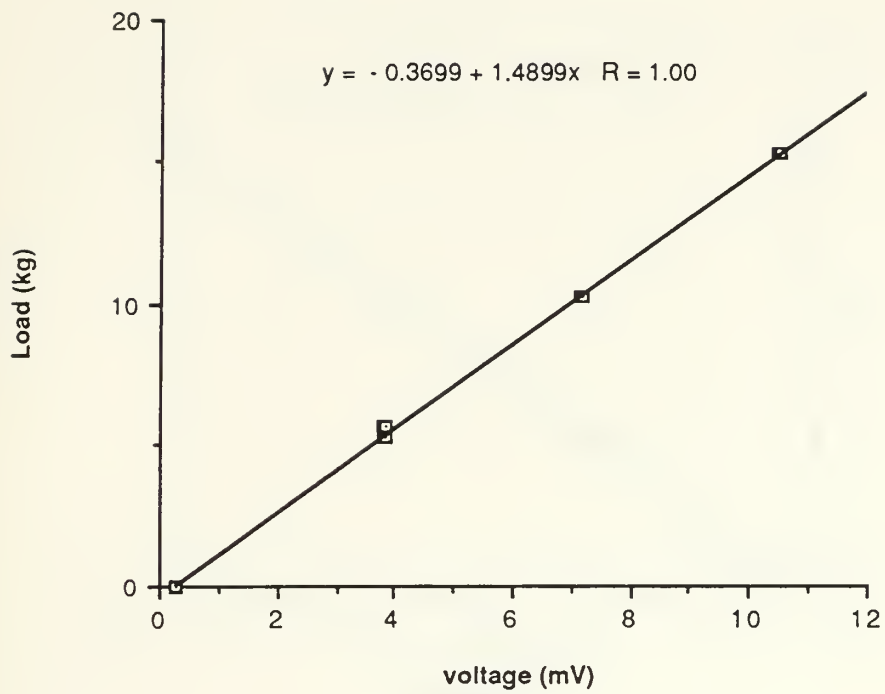


## Load Cell 2 Calibration

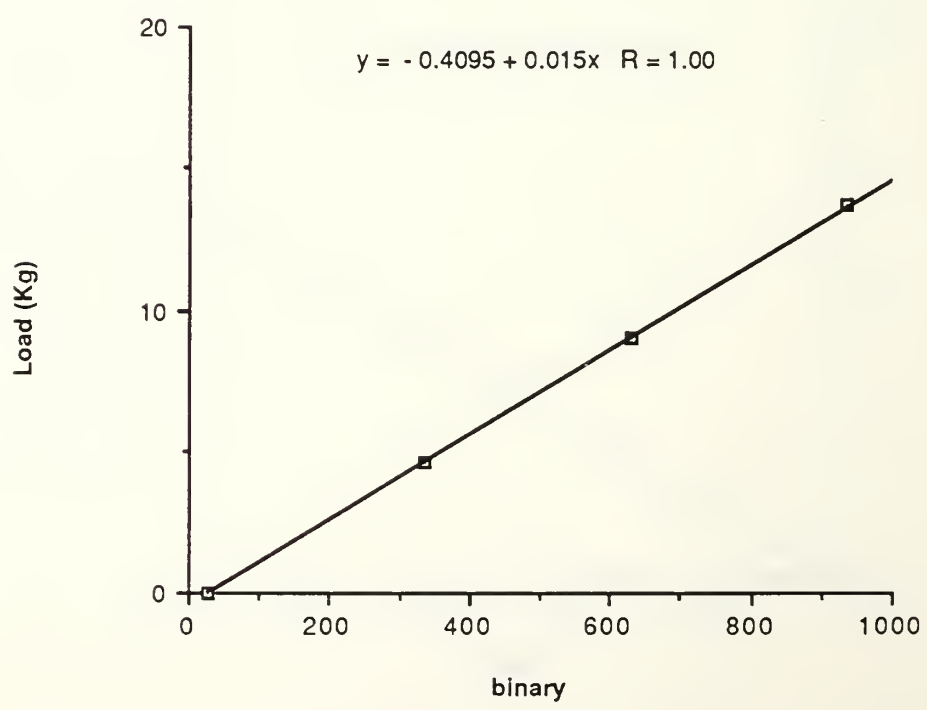
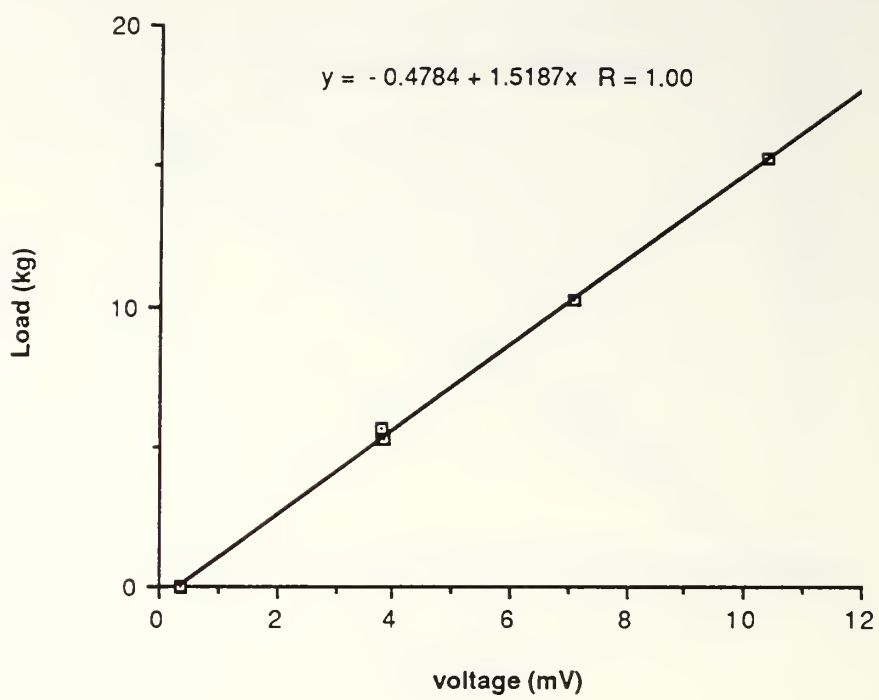




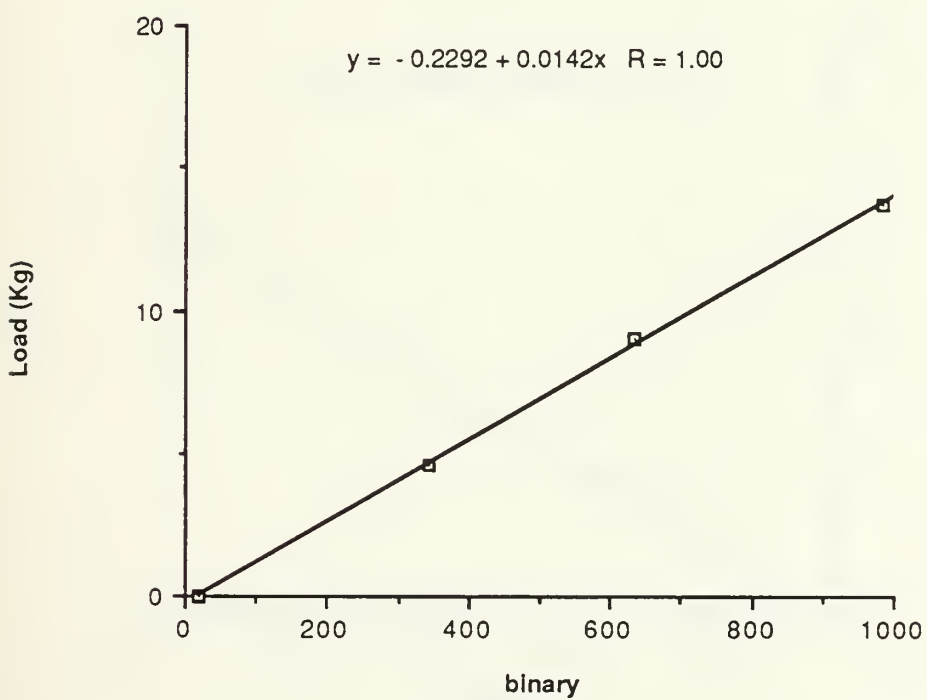
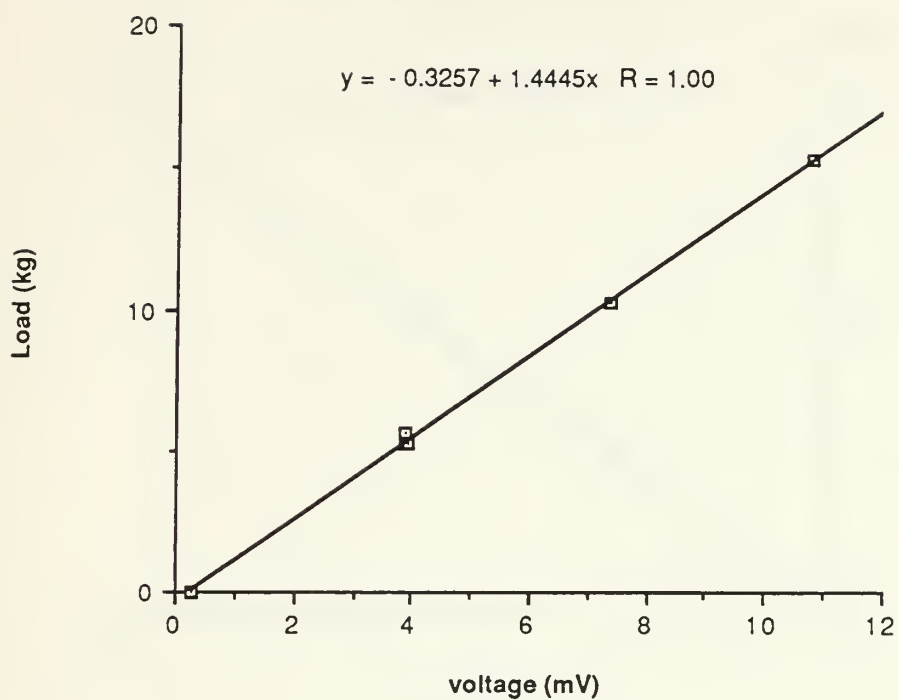
## Load Cell 3 Calibration



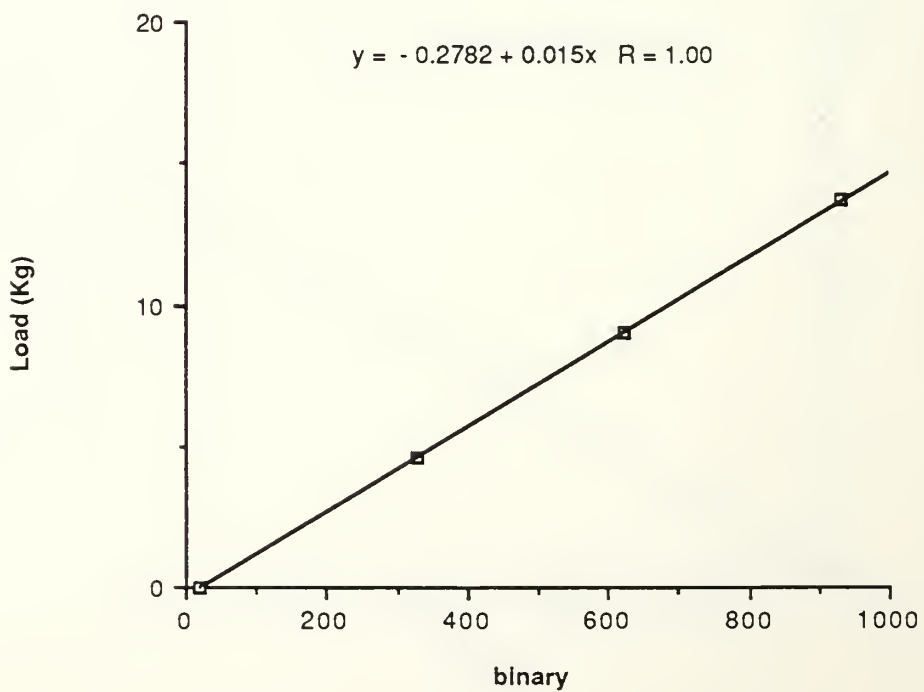
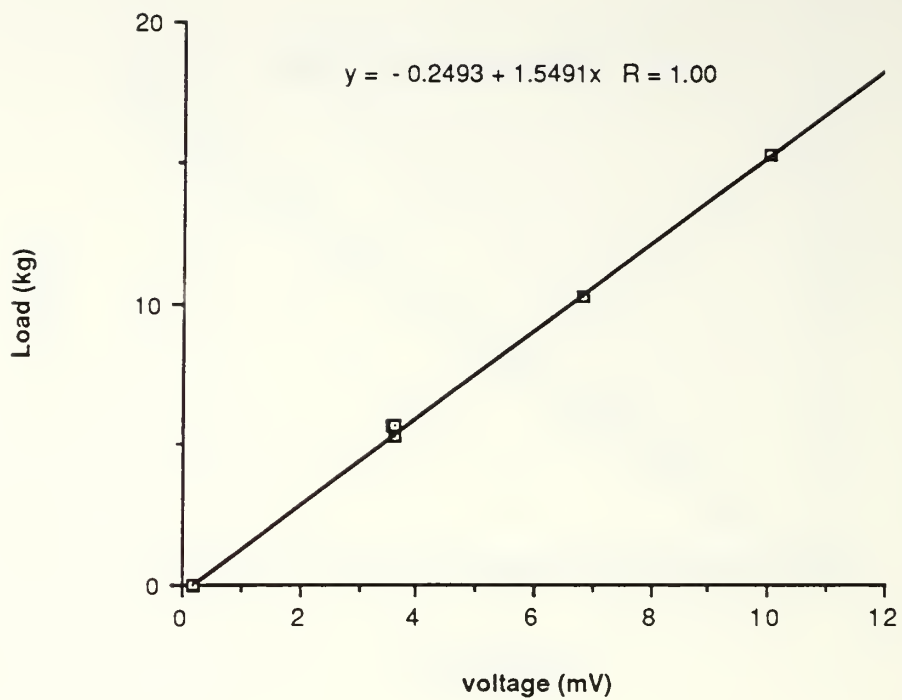
# Load Cell 4 Calibration



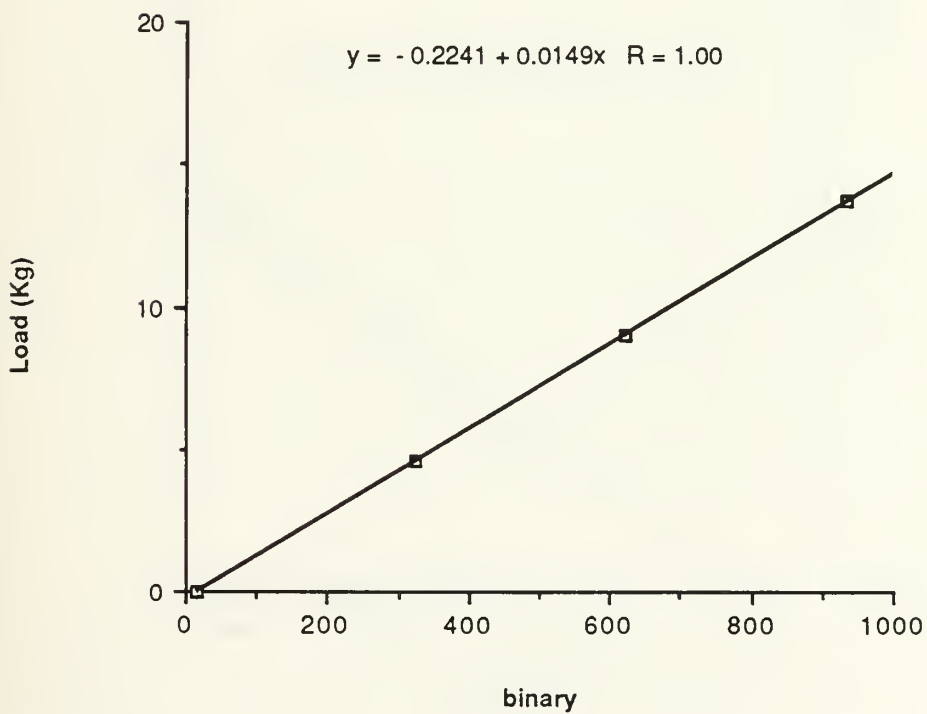
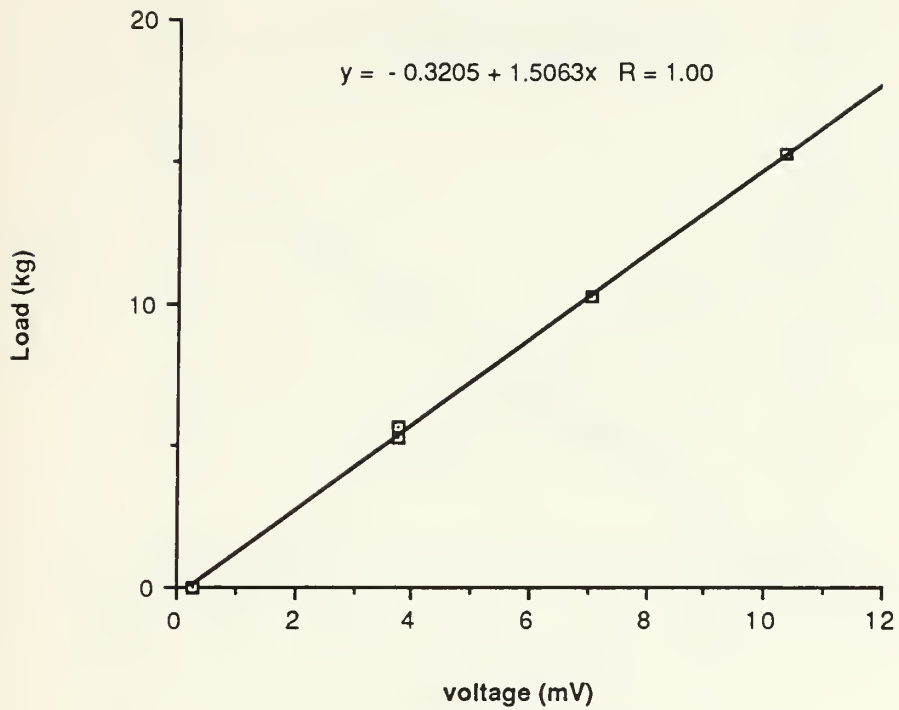
## Load Cell 5 Calibration



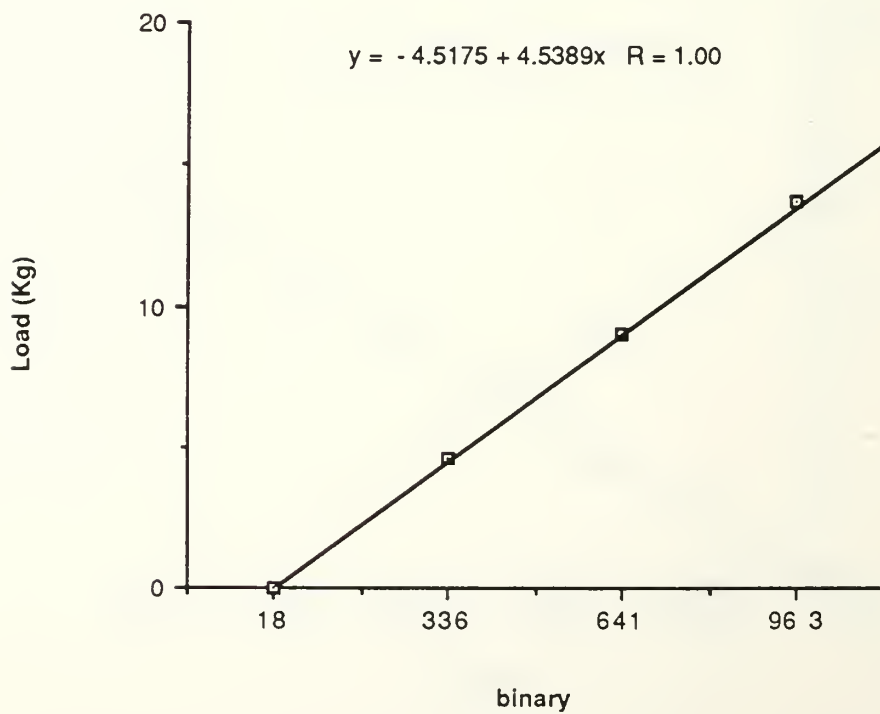
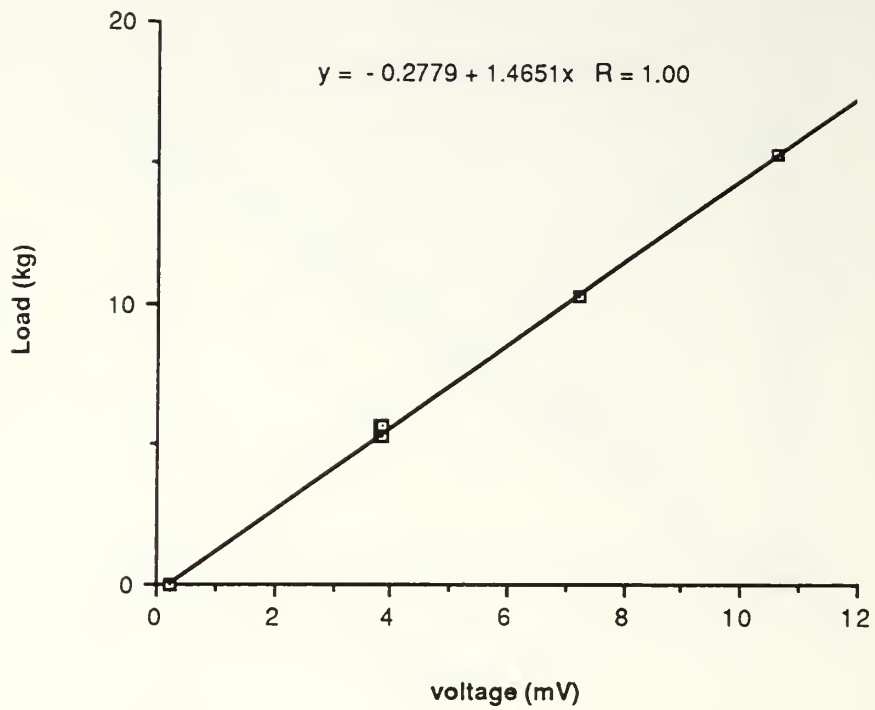
## Load Cell 6 Calibration



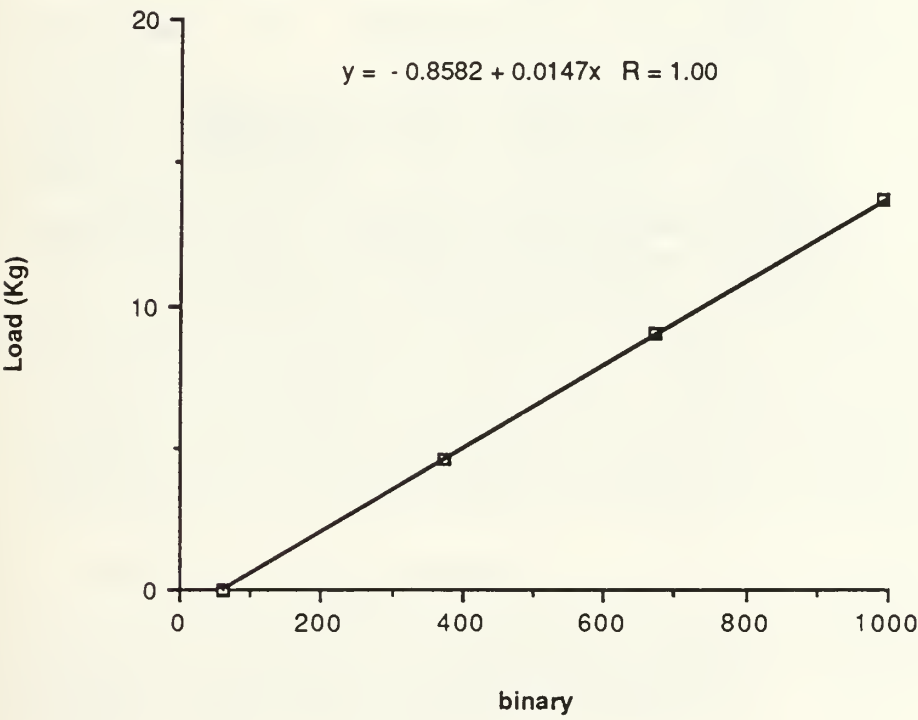
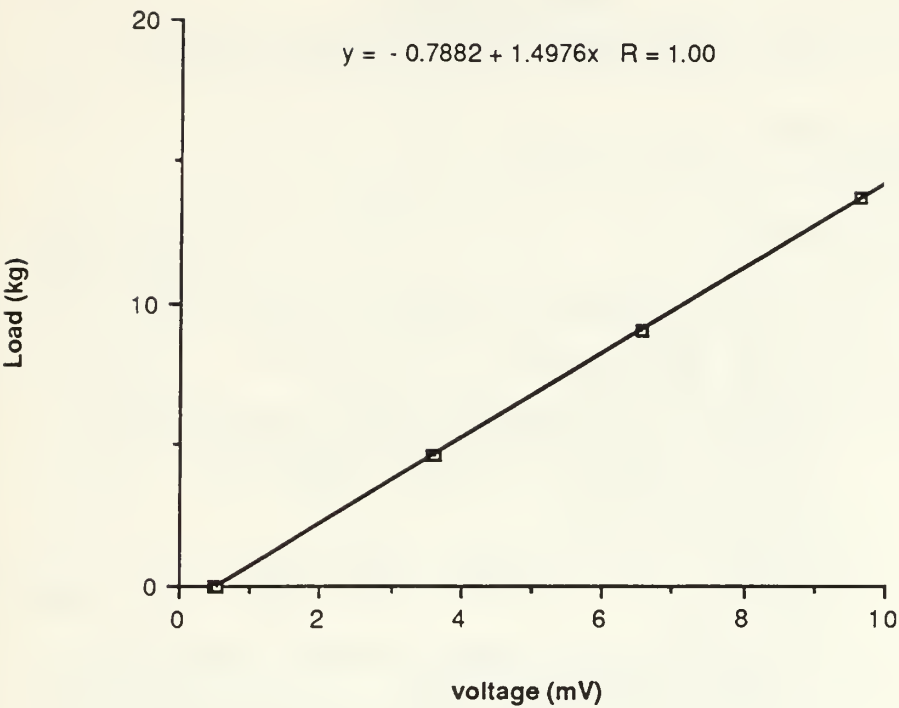
## Load Cell 7 Calibration



## Load Cell 8 Calibration



# Load Cell 9 Calibration





APPENDIX E  
Fast Data Acquisition Code Listing

1. LMENU.BAS
2. LMENUCL.BAS

VARIABLE LISTING:

CHAN(i)	=	analog channel array
GAIN(i)	=	gain array
ADDRESS	=	AtoD address of the card
NCHANS	=	number of channels to be initialized
CHANNEL	=	Direct Memory Access channel
ADRESS	=	Timer address of the card
Z	=	loop counter
PERIOD	=	scalar to set the sweep rate
NSWEEPS	=	number of sweeps required for time time interval
B\$	=	file name for data storage on disk
TIMNUM	=	Timer channel number
COUNT	=	determines the clock for the board
X,Y,S,T	=	dummy variables
SWTIME	=	number of interrupts to skip between readings
NCHANS	=	how many channels for each sweep
FIRST	=	starting channel for the sweep
NSWEEP	=	check variable for determining when the number of sweeps are taken
HANDLE	=	file number which equates to a filename when LABPAC opens a file
RESULT	=	varies, see Ref 4 for meaning

LMENU10.BAS

```
5 '           Data aquisition software for Bundle Life
Testing
10 '           written by J. W. Emery
15 '           June 1988
20 '
25 ' This program is designed to aquire data from the
    Labmaster
26 ' data aquisition board using Scientific Solution's
    supplied software
27 ' "LABPAC". LABPAC is a memory resident program which
    defines
28 ' the functions needed to control the data aquisition
    card. See the
29 ' LABPAC user manual for more information.
40 '
45 '
50 GOSUB 7405
95 '
96 ' DEFINE THE LABMASTER CONTROL FUNCTIONS FOR LABPAC;
    SUPPLIED
97 ' WITH THE LABMAST.BAS FILE
98 '
100 DEFINT A-Z
200 DEF SEG=0
300 LABSEG= PEEK(971)*256 + PEEK(970)
400 LABPAC= PEEK(969)*256 + PEEK(968)
500 DEF SEG= LABSEG
600 LRESET=0:INTCLR=1:INTSET=2:BCD=3:LBIN=4
700 AIINIT=5:DINIT=6:AOINIT=7:SWINIT=8:TIINIT=9
800 AIRAW=10:DIRAW=11:AORAW=12:DORAW=13:TIRAW=14
900 AIMAX=15:DIMAX=16:AOMAX=17:DOMAX=18:TILH=19
1000 AISWST=20:DISWST=21:AOSWST=22:DOSWST=23:TIST=24
1100 AISTAT=25:DISTAT=26:AOSTAT=27:DOSTAT=28:TISTAT=29
1200 AISWAB=30:DISWAB=31:AOSWAB=32:DOSWAB=33:TIAB=34
1300 AIHDW=40:DIHDW=41:DOHDW=42:DOCLR=43:DOSET=44
1400 AISC=45:DISC=46:AORSWST=47:DORSWST=48:AIDMA=49
1500 LCREATE=35:LOPEN=36:LREAD=37:LWRITE=38:LCLOSE=39
1600 '
1610 ' INITIALZE THE VARIABLES
1620 '
1700 PERIOD=0:INTERRUPT=0:ADDRESS=0:MODE=0:SWTIME=0
1800 NCHANS=0:TIMNUM=0:NSWEEP=0:NSWEEPS=0
1900 CHANNEL=0:NCHANS=0:START=0:RESULT=0
2000 I=0:J=0:OUTPUT=0:FIRST=0
```

```

2100 COUNT=0:ADRESS=0:Z=0
2200 A$=SPACE$(1):B$=SPACE$(50)
2300 DIM CHAN(255),DATBUF(15999),GAIN(255)
2400 '
2500 ' ESTABLISH THE CHANNEL AND GAIN ARRAYS
2700 '
2800 FOR J = 0 TO 18          'CHANNEL ARRAY SET-UP.  THE
CHANNELS                     BEING USED ARE 8 - 17.  THE
2810 '                       INITIALIZING
2820 '                       ROUTINE STARTS WITH CHANNEL
0. 2900 CHAN(J) = J
3300 GAIN(J) = 3
3400 NEXT J
3500 '
3504 ' RESET THE SYSTEM
3506 '
3510 CALL LABPAC(RESULT,LRESET)
3520 IF RESULT < 0 THEN GOTO 7070 'print error
3530 '
3600 ADDRESS = 1812 'SET THE ATOD ADDRESS OF THE BOARD
3700 NCHANS = 18 'THE NUMBER OF CHANNELS YOU WANT TO USE
3710 ' IT STARTS WITH ZERO
3800 CHANNEL = 0 ' THE DMA CHANNEL, 0 = DISABLED
3810 '
3820 'INITAILZE THE CHANNELS
3830 '
3 9 0 0      C A L L
LABPAC(ADDRESS,NCHANS,CHANNEL,GAIN(0),RESULT,AIINIT)
4000 IF RESULT <> 0 THEN GOTO 7070 'print error
4100 '
4200 ADRESS = 1816          'SET THE TIMER ADDRESS
4210 '
4220 ' INITIALZE THE TIMER
4230 '
4300 CALL LABPAC(ADRESS,RESULT,TIINIT)
4400 IF RESULT <> 0 THEN GOTO 7070 'print error
4500 '
4520 FOR Z = 1 TO 13
4550 READ T,S,X,Y,B$
4600 TIMNUM = 1 'DECLARE THE TIMER CHANNEL
4700 COUNT = S 'SET THE TIMER SOURCE SEE LABPAC
MANUAL
4800 PERIOD = X 'SCALAR TO DIVIDE COUNT BY TO SET
4810 '          INTERRUPT RATE.  DIVIDE THE
INTERRUPT

```

```

4820 '                RATE BY FOUR TO GET THE SWEEP RATE
4830 '                14 = 1000 Hz
4835 '
4840 ' INITIALZE THE SWEEP
4850 '
4900 CALL LABPAC(TIMNUM, COUNT, PERIOD, RESULT, TIST)
5000 IF RESULT <> 0 THEN GOTO 7070 'print error
5200 INTERRUPT = 7 'SET THE INTERRUPT
5300 CALL LABPAC(TIMNUM, INTERRUPT, RESULT, SWINIT)
5400 IF RESULT <> 0 THEN GOTO 7070 'print error
5500 '
5600 SWTIME = T 'NUMBER OF INTERRUPTS TO SKIP A
READING
5700 NSWEEPS = Y 'NUMBER OF SWEEPS REQUIED FOR THE
DELTA T
5800 NCHANS = 10 'HOW MANY CAHNNELS TO READ
5900 FIRST = 8 'WHAT CHANNEL TO START WITH
5910 '
5920 'COLLECT THE DATA
5930 '
6000 CALL LABPAC(SWTIME, NSWEEPS, NCHANS
..., CHAN(FIRST), DATBUF(0), RESULT, AISWST)
6100 IF RESULT < 0 THEN GOTO 7070 'print error
6200 '
6210 ' CHECK TO SEE IF ALL THE DATA IS COLLECTED
6220 '
6300 NSWEEP= 0:CALL LABPAC(NSWEEP, RESULT, AISTAT)
6310 '
6320 'DEFINE THE OUTPUT FILE, CREATE IT AND WRITE THE
DATA TO IT
6330 '
6400 '
6500 CALL LABPAC(B$, RESULT, LCREATE)
6600 IF RESULT < 0 THEN GOTO 7070 'print error
6700 HANDLE = RESULT
6800 CALL LABPAC(HANDLE, NSWEEPS, NCHANS
..., CHAN(FIRST), DATBUF(0), RESULT, LWRITE)
6900 IF RESULT <> 0 THEN GOTO 7070 'print error
6950 CALL LABPAC(HANDLE, RESULT, LCLOSE)
7000 '
7005 CLS
7010 PRINT"I HAVE FINISHED "; Z ;" RATE INTERVALS."
7015 GOSUB 7405
7020 NEXT Z
7030 '
7040 GOTO 7570

```

```

7050  '
7060  THE ERROR TABLE AS SUPPLIED BY SCIENTIFIC SOLUTIONS
7070  '
7080      ON      RESULT-&H8000      GOTO
7100,7110,7120,7130,7140,7150,7160,7170
7090  PRINT "UNKNOWN ERROR CODE "; HEX$(RESULT): GOTO
7570
7100  PRINT "PARAM"; :GOTO 7570
7110  PRINT "RANGE"; :GOTO 7570
7120  PRINT "OVERRUN";:GOTO 7570
7130  PRINT "TABLE"; :GOTO 7570
7140  PRINT "FILERR"; :GOTO 7570
7150  PRINT "DMAERR"; :GOTO 7570
7160  PRINT "TIMERR"; :GOTO 7570
7170  PRINT "DIMENSION";
7180  '
7190  'CLOSE THE DATA FILES
7200  '
7210  CALL LABPAC(RESULT,LRESET)
7220  KEY ON
7230  DEF SEG
7240  '
7250  'DEFINE THE DATA FOR THE SWEEP RATES AND TIME
INTERVAL
7260  '
7265  DATA 1,14,25,1500 ,RUN1.DAT
7270  DATA 1,14,25,1500 ,RUN2.DAT
7280  DATA 1,14,1500,50 ,RUN3.DAT
7290  DATA 1,14,2250,34 ,RUN4.DAT
7300  DATA 1,14,3000,25 ,RUN5.DAT
7310  DATA 1,14,12e3,75 ,RUN6.DAT
7320  DATA 1,14,21e3,43 ,RUN7.DAT
7330  DATA 1,14,30e3,30 ,RUN8.DAT
7340  DATA 1,15,12e3,75 ,RUN9.DAT
7345  DATA 1,15,21e3,43 ,RUN10.DAT
7350  DATA 1,15,30e3,30 ,RUN11.DAT
7360  DATA 4,15,30e3,75 ,RUN12.DAT
7370  DATA 7,15,30e3,43 ,RUN13.DAT
7380  DATA 10,15,30e3,30 ,RUN14.DAT
7390  '
7400  GOTO 7570
7405  '
7410  PRINT
7420  PRINT
7430  PRINT
7440  PRINT

```

```

7450 PRINT
7460 PRINT
7470 PRINT"*****"
7480 PRINT"*"
7490 PRINT"* BUNDLE LIFE TESTING IN PROGRESS"
7500 PRINT"*"
7510 PRINT"*I AM COLLECTING DATA AT DESIGNED INTERVALS"
      "*"
7520 PRINT"*"
7530 PRINT"* DO NOT DISTURB ME UNTIL I FINISH"
7540 PRINT"*"
7      5              5
PRINT"*****"
7560 RETURN
7570 END
0

```



# LMENUCAL.BAS

```
5 '      Data aquisition software for Calibration of the
Equipment
10 '      written by J. W. Emery
15 '      June 1988
20 '
25 ' This program is designed to aquire data from the
Labmaster
26 ' data aquisition board using Scientific Solution's
supplied software
27 ' "LABPAC". LABPAC is a memory resident program which
defines
28 ' the functions needed to control the data aquisition
card. See the
29 ' LABPAC user manual for more information.
40 '
45 '
50 GOSUB 7405
95 '
96 ' DEFINE THE LABMASTER CONTROL FUNCTIONS FOR LABPAC;
SUPPLIED
97 ' WITH THE LABMAST.BAS FILE
98 '
100 DEFINT A-Z
200 DEF SEG=0
300 LABSEG= PEEK(971)*256 + PEEK(970)
400 LABPAC= PEEK(969)*256 + PEEK(968)
500 DEF SEG= LABSEG
600 LRESET=0:INTCLR=1:INTSET=2:BCD=3:LBIN=4
700 AIINIT=5:DINIT=6:AONIT=7:SWINIT=8:TIINIT=9
800 AIRAW=10:DIRAW=11:AORAW=12:DORAW=13:TIRAW=14
900 AIMAX=15:DIMAX=16:AOMAX=17:DOMAX=18:TILH=19
1000 AISWST=20:DISWST=21:AOSWST=22:DOSWST=23:TIST=24
1100 AISTAT=25:DISTAT=26:AOSTAT=27:DOSTAT=28:TISTAT=29
1200 AISWAB=30:DISWAB=31:AOSWAB=32:DOSWAB=33:TIAB=34
1300 AIHDW=40:DIHDW=41:DOHDW=42:DOCLR=43:DOSET=44
1400 AISC=45:DISC=46:AORSWST=47:DORSWST=48:AIDMA=49
1500 LCREATE=35:LOPEN=36:LREAD=37:LWRITE=38:LCLOSE=39
1600 '
1610 ' INITIALZE THE VARIABLES
1620 '
1700 PERIOD=0:INTERRUPT=0:ADDRESS=0:MODE=0:SWTIME=0
1800 NCHANS=0:TIMNUM=0:NSWEEP=0:NSWEEPS=0
1900 CHANNEL=0:NCHANS=0:START=0:RESULT=0
2000 I=0:J=0:OUTPUT=0:FIRST=0
```



```

2100 COUNT=0:ADRESS=0:Z=0
2200 A$=SPACE$(1):B$=SPACE$(50)
2300 DIM CHAN(255),DATBUF(15999),GAIN(255)
2400 '
2500 ' ESTABLISH THE CHANNEL AND GAIN ARRAYS
2700 '
2800 FOR J = 0 TO 18          'CHANNEL ARRAY SET-UP.  THE
CHANNELS
2810 '                      BEING USED ARE 8 - 17.  THE
INITIALIZING
2820 '                      ROUTINE STARTS WITH CHANNEL
0.
2900 CHAN(J) = J
3300 GAIN(J) = 3
3400 NEXT J
3500 '
3504 ' RESET THE SYSTEM
3506 '
3510 CALL LABPAC(RESULT,LRESET)
3520 IF RESULT < 0 THEN GOTO 7070 'print error
3530 '
3600 ADDRESS = 1812 'SET THE ATOD ADDRESS OF THE BOARD
3700 NCHANS = 18    'THE NUMBER OF CHANNELS YOU WANT TO
USE
3710                ' IT STARTS WITH ZERO
3800 CHANNEL = 0    ' THE DMA CHANNEL, 0 = DISABLED
3810 '
3820 'INITAILZE THE CHANNELS
3830 '
3900 CALL LABPAC(ADDRESS,NCHANS
...,CHANNEL,GAIN(0),RESULT,AIINIT)
4000 IF RESULT <> 0 THEN GOTO 7070 'print error
4100 '
4200 ADRESS = 1816          'SET THE TIMER ADDRESS
4210 '
4220 ' INITIALZE THE TIMER
4230 '
4300 CALL LABPAC(ADRESS,RESULT,TIINIT)
4400 IF RESULT <> 0 THEN GOTO 7070 'print error
4500 '
4550 READ T,S,X,Y
4600 TIMNUM = 1 'DECLARE THE TIMER CHANNEL
4700 COUNT = S 'SET THE TIMER SOURCE SEE LABPAC MANUAL
4800 PERIOD = X 'SCALAR TO DIVIDE COUNT BY TO SET
4810 '                      INTERRUPT RATE.  DIVIDE THE
INTERRUPT

```

```

4820 '          RATE BY FOUR TO GET THE SWEEP RATE
4830 '          14 = 1000 Hz
4835 '
4840 ' INITIALZE THE SWEEP
4850 '
4900 CALL LABPAC(TIMNUM, COUNT, PERIOD, RESULT, TIST)
5000 IF RESULT <> 0 THEN GOTO 7070 'print error
5200 INTERRUPT = 7 'SET THE INTERRUPT
5300 CALL LABPAC(TIMNUM, INTERRUPT, RESULT, SWINIT)
5400 IF RESULT <> 0 THEN GOTO 7070 'print error
5500 '
5600 SWTIME = T 'NUMBER OF INTERRUPTS TO SKIP A READING
5700 NSWEEPS = Y'NUMBER OF SWEEPS REQUIED FOR THE DELTA T
5800 NCHANS = 10 'HOW MANY CAHNNELS TO READ
5900 FIRST = 8 'WHAT CHANNEL TO START WITH
5910 '
5920 'COLLECT THE DATA
5930 '
6000 CALL LABPAC(SWTIME, NSWEEPS, NCHANS
..., CHAN(FIRST), DATBUF(0), RESULT, AISWST)
6100 IF RESULT < 0 THEN GOTO 7070 'print error
200 '
6210 ' CHECK TO SEE IF ALL THE DATA IS COLLECTED
6220 '
6300 NSWEEP= 0:CALL LABPAC(NSWEEP, RESULT, AISTAT)
6310 '
6320 'DEFINE THE OUTPUT FILE, CREATE IT AND WRITE THE
DATA TO IT
6330 '
6400 '
6450 Print "Input data filrname."
6460 input B$
6500 CALL LABPAC(B$, RESULT, LCREATE)
6600 IF RESULT < 0 THEN GOTO 7070 'print error
6700 HANDLE = RESULT
6800 CALL LABPAC(HANDLE, NSWEEPS, NCHANS
..., CHAN(FIRST), DATBUF(0), RESULT, LWRITE)
6900 IF RESULT <> 0 THEN GOTO 7070 'print error
6950 CALL LABPAC(HANDLE, RESULT, LCLOSE)
7000 '
7040 GOTO 7570
7050 '
7060 THE ERROR TABLE AS SUPPLIED BY SCIENTIFIC SOLUTIONS
7070 '
7080 ON RESULT-&H8000 GOTO
7100, 7110, 7120, 7130, 7140, 7150, 7160, 7170

```

```

7090 PRINT "UNKNOWN ERROR CODE "; HEX$(RESULT): GOTO
7570
7100 PRINT "PARAM"; :GOTO 7570
7110 PRINT "RANGE"; :GOTO 7570
7120 PRINT "OVERRUN";:GOTO 7570
7130 PRINT "TABLE"; :GOTO 7570
7140 PRINT "FILERR"; :GOTO 7570
7150 PRINT "DMAERR"; :GOTO 7570
7160 PRINT "TIMERR"; :GOTO 7570
7170 PRINT "DIMENSION";
7180 '
7190 'CLOSE THE DATA FILES
7200 '
7210 CALL LABPAC(RESULT,LRESET)
7220 KEY ON
7230 DEF SEG
7240 '
7250 'DEFINE THE DATA FOR THE SWEEP RATES AND TIME
INTERVAL
7260 '
7265 DATA 1,14,25,20 ,RUN1.DAT
7390 '
7400 GOTO 7570
7405 '
7570 END

```

APPENDIX F  
Fast Data Acquisition Procedures

I. Calibration

A. Verify the load cell and LDVT power supplies are outputting 5 and 24 volts.

B. Calibrate the % load meter on the Instron machine.

1. Take readings with 0,5,15,10,5,0 (or suitable intervals). The unloading checks for hysteresis.
2. Repeat to check for repeatability.
3. Plot and curve fit the data as load vs. % load.

C. Calibrate the load cells

1. Execute LABPAC program.
2. Connect a voltmeter to the load cell to be calibrated.
3. Hang known weights over the expected range as in B1.
4. Take a reading in millivolts and binary. The binary reading can be obtained from LMENUCAL.BAS.
5. Repeat for a repeatability check.
6. Plot and curve fit both sets of data as load vs. volt/binary.

D. Calibrate the LDVT

1. Mount the LDVT on an accurate displacement measurer.
2. Connect a voltmeter.
3. Zero the LDVT using the voltmeter.
4. Move the shaft known distances in both directions taking volt and binary readings (use LMENUCAL.BAS for the binary readings).
5. Repeat for a repeatability check.
6. Plot and curve fit both sets of data as load vs. volt/binary.

## II. Bundle Test

### A. Mount the Samples

1. Ensure the manual/auto switch is in the manual position.
2. Verify the load cell and LDVT power supplies are outputting 5 and 24 volts.
3. Hang a 2 Kg weight on each load cell and record the millivolt reading.
4. Loosen the nuts on the differential screws.
5. Mount the samples.
6. Adjust the load on the samples with the differential screw until the 2 Kg reading is reached. Tighten the nuts.
7. Relax the load and let rest overnight.

### B. Begin the Test.

1. Set the crosshead speed to 20/1 and the variable knob to the second mark from the "min" setting.
2. Set the tension/compression switch to tension.
3. Set the ENG/SI switch to SI.
4. Set the high and low limits on the 700 control unit.
5. Verify the load cell and LDVT power supplies are outputting 5 and 24 volts.
6. Start LMENU.BAS
7. Switch the manual/auto switch to auto.
8. Verify the machine loads to the desired load.
9. After 15 days switch to the slow data acquisition system.

## III. Data Transfer

- A. Transfer the data before running LMENU10.BAS again. The data will be written over.
- B. Use a text editor to strip the first few lines.
- C. Set up the spreadsheet time column.
- D. Import the data file at the correct place one after the other (1-14).

## APPENDIX G

### Slow Data Acquisition Procedures

1. Set-up the HP units in series. Order is not important since commands are passed to the next unit if it does not recognize.

2. Format Cassette Tapes

Insert tape  
Execute the following commands  
XEQ ALPHA NEWM ALPHA 447  
(This will give a maximum number of data files per tape.)

3. Ensure the Data Acquisition/Control ROM PAC is inserted into the HP 41.

4. Set the date and time in the HP 41.

5. Allocate registers in the HP 41:

Minimum of 38 plus one for each channel to be read.  
XEQ ALPHA SIZE ALPH 048

6. Execute the Data Logger program:

XEQ ALPHA DL ALPHA  
Answer the questions as shown in the ROM PAC manual as follows:

New Y/N:	if first time Y R/S
First Ch:	3
Last Ch:	13
Function:	DVC
First Ch:	R/S
Record:	N
Print:	Y
Interval:	24.0000
Iterations:	100 (or any convenient number)
Start Time:	R/S
Start Date:	R/S

Periodically check the paper roll in the printer, replace when needed.

Repeat every 100 days  
Enter data into the spreadsheet.



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